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Atlas of Water Cooperation and Conflicts

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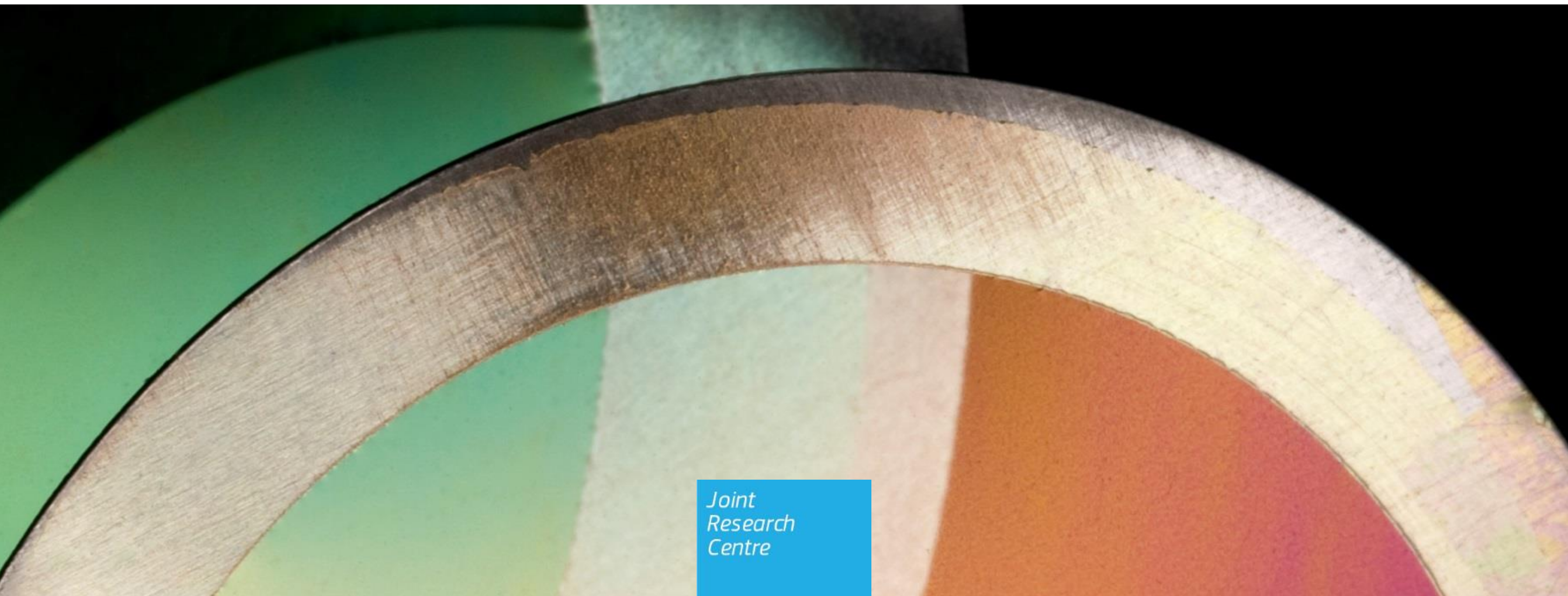

Joint Research Centre

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Acknowledgements

This report brings together contributions from colleagues and external experts that, over the time, worked on this project. In particular the study was first designed by A. Reynaud that conducted the first literature review and data selection, designed the conceptual framework, and started the analysis. Two external experts, M. Couttenier and R. Soubeyran, conducted the statistical analysis and presented their results in a document that is incorporated in this report. G. Ceccherini contributed with extremely useful suggestions and advices on the analysis of the data. The Authors would like to thank Ad de Roo for making water stress indicators and climate data available.

Authors

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Abstract

The concept of Atlas of Water Conflict and Cooperation refers to an empirically based tool aimed at analyzing the interactions between biophysical and socio-economic factors able to influence cooperation or tensions over water in shared watersheds. The idea was to develop a tool able to monitor availability, uses and abuses of water and water-stressed hot spots at national and regional scales. This is not only directed at analyzing water supply and demand, as for a water stress indicator, but also the socio-economic, institutional, legal, and cultural context evolutions that are likely to influence the hydro-political tensions or cooperation.

The aim of this product is to provide the policy maker with a flexible instrument able to capture historical and current trends of factors relevant for water related issues, but also the possibility to interactively construct future scenarios and eventually simulate different sets of policy options and strategies.

This first version of the Atlas of Water Conflict and Cooperation is based on the global assessment of water related issues and their correlates in the interactions between countries sharing transboundary watersheds. The analysis is based on the information about the bi-lateral interactions of the countries sharing the existing 276 international river basins (IRCC database).

The Atlas is designed under a framework structured adopting concepts from political science and environmental economics. Three main groups of indicators are highlighted: river basin freshwater availability; human pressure on water resources; global restrains. A combination of econometric and statistical approaches and tools derived by machine learning have been used to test correlation and causality of the indicators from each of the three groups with historical episodes of water related tensions or cooperation. The relative impact of each time-varying and time-invariant indicator is in this way assessed and empirically estimated.

1 Introduction

Future availability of freshwater for human consumption under a changing world represents one of the main concerns of the actual political debate. Water crises are identified as one of the highest factors of risk for the next 10 years by the Global Risks Perception Survey conducted yearly by the World Economic Forum (WEF 2016). The increasing demographic pressure, environmental degradation, and climate change impacts on water spatial and temporal distribution represent the largest determinants of actual and future water related issues. Although it is intuitive that water stress is likely to increase the competition over water, it is not completely clear how the combinations of factors influencing water demand and availability alone could lead to such different situations in different watersheds spread around the world. Several indicators monitoring water availability and water demand have been, in fact, developed in the recent past (see for instance UNEP 2008), but evidence shows that the consequences of similar levels of physical water stress, both caused by shocks on the supply or demand sides, have been handled unevenly in different areas of the world and in different historical contexts. On the one hand, resource scarcity is likely to increase tensions and conflicts, but, on the other hand, the lack of a vital resource as water is also likely to boost cooperation between actors sharing the same freshwater sources. Although several episodes of tensions, in the large majority of the cases non-violent, were also recorded, literature about hydro-political tensions proved that, in the case of transboundary basins, water related issues have been more likely resolved with cooperation between the countries sharing the watersheds (De Stefano, Edwards, et al. 2010; Yoffe et al. 2003; Yoffe et al. 2004). The analysis of the historical events brought to the conclusion that physical availability of water and water demand components are only part of the aspects to be taken into consideration for the analysis of water related issues (Böhmelt et al. 2014). Literature about political science, geopolitics and diplomacy showed that also socio-economic factors, jointly with institutional capacity, legal framework, and cultural background, have a close relation with the diplomatic interactions between countries or actors sharing resources ([1]).

The concept of Atlas of Water Conflict and Cooperation refers to an empirically based tool aimed at analyzing the interactions between biophysical and socio-economic factors able to influence cooperation or tensions over water in shared watersheds. The idea was to develop a tool able to monitor availability, uses and abuses of water and water-stressed hot spots at national and regional scales. This was not only directed at analyzing water supply and demand, as for a water stress indicator, but also the socio-economic, institutional, legal, and cultural context evolutions that are likely to influence the hydro-political tensions or cooperation. The aim is to provide the policy maker with a flexible instrument able to capture historical and current trends of factors relevant for water related issues, but also the possibility to interactively construct future scenarios and eventually simulate different sets of policy options and strategies.

This first version of the Atlas of Water Conflict and Cooperation is based on the global assessment of water related issues and their correlates in the interactions between countries sharing transboundary watersheds. The analysis is based on the information about the existing 276 international river basins shared by two or more countries and their bi-lateral interactions. The Atlas is designed under a framework structured adopting concepts from political science and environmental economics. Three main groups of indicators are highlighted: river basin freshwater availability; human pressure on water resources; global restrains. A combination of econometric and statistical approaches and tools derived by machine learning have been used to test correlation and causality of the indicators from each of the three groups with historical episodes of water related tensions or cooperation. The relative impact of each time-varying and time-invariant indicator is in this way assessed and empirically estimated. The historical water related issues database

[1] An overview about this topic is provided by, among others, the Correlates of War Project (http://www.correlatesofwar.org/)

for the analysis is the International River Basin Conflict and Cooperation – IRCC (Kalbhenn & Bernauer 2012).

The graphical tool is structured with the combination of a geoServer to maintain the geographic data and making them available, a PostGIS database to store geodata on the server side, and a client web-based tool designed to display and manipulate the stored information. In the client side, the tool proposed is a reusable component, programmed with Javascript and several geographic libraries that could be incorporated in any website that might need a geographic component with the functionality of the Atlas.

The designed graphical tool is organized to interactively display: maps, map controls, operation widgets, layers panels, and charting tools. The instrument is designed to be extremely flexible and user friendly. The information is visualized at the river basin level or at raster level when available.

Data about biophysical and socio-economic variables are displayed as either raster or vectorial layers. The result is a collection of data time series with the data sampled at a detailed spatial and temporal resolution. The tool provides the controls needed to display the evolution on the data over time.

2 Review of similar online products and literature review on water conflict and cooperation

The Atlas of Water Conflict and Cooperation is presented as an online tool aimed at monitoring the evolution of the factors determining the likelihood of cooperative or confrontational behavior over water related issues. In this section, we present existing web products designed in a similar way and the review of the methodologies for the quantitative analyses behind the aggregation of the data in the Atlas.

2.1 Similar products

Instruments shaped on ideas similar to the ones behind the Atlas of Water Conflict and Cooperation are currently available online. In this report, we refer to two of them (**Figure 1**): the *AQUEDUCT Water Risk Atlas* ([2]) developed by the World Resources Institute (WRI) (Gassert et al. 2013); and the *Transboundary Waters Assessment Programme (TWAP) River Basin Data Portal* ([3]) developed by a consortium of nine partners led by United Nations Environment Programme (UNEP) – DHI Partnership (UNEP-DHI & UNEP 2016).

The WRI product refers to a global database of 12 main indicators from about 15,000 basins from all world that, once aggregated, form a composite index defined as Overall Water Risk (Reig et al. 2013). The indicators are grouped into three main categories:

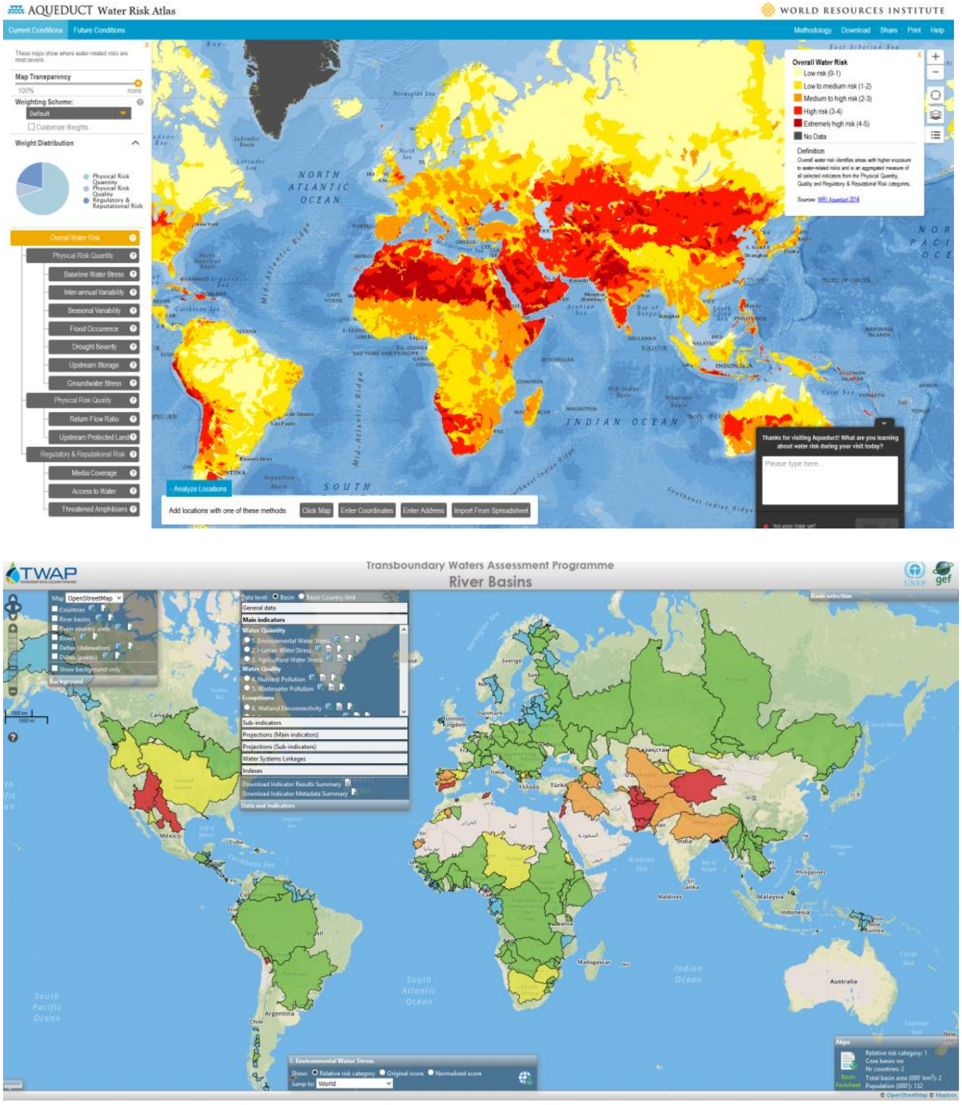
1. Quantity – Physical Risk:
    - Baseline water stress; inter-annual variability; seasonal variability; flood occurrence; drought severity; upstream storage; groundwater stress.
2. Quality – Physical Risk:
    - Return flow ratio; upstream protected land.
3. Regulatory and Reputational Risk:
    - Media coverage; access to water; threatened amphibian.

In order to ensure readability, each of the indicators is presented in a normalized form. The aggregation is ensured through a weighted average methodology. The weights are assigned in a logarithmic scale corresponding to a "Very low" to "Very high" range. The weighting profile could be changed by the user: ten different profiles are available. Each of the profiles is designed in order to represent the relative importance between the indicators of each of the three groups for a specific industrial sector respect to a default one. This allow to shape the risk indicator giving more relevance to the specific priorities of the user. The represented industries are: agriculture, food & beverage, chemicals, electric power, semiconductor, oil & gas, mining, construction materials, textile (Reig et al. 2013). The normalization and aggregation of the indicators was later updated involving a more detailed quantitative analysis, and the product was developed in order to offer the possibility to display the future evolution of the indicators over possible scenarios (Gassert et al. 2014). Future scenarios are available for four indicators, all of them related to the first group (**quantity**), namely: water stress, seasonal variability, water supply, and water demand. The scenarios are two or three, depending on the indicator, basing on a *Business as usual* and diverging towards more *optimistic* or *pessimistic* trends. The time horizon goes up to 2040.

[2] http://www.wri.org/applications/maps/aqueduct-atlas/#x=28.24&y=-0.89&s=ws!20!28!c&t=waterrisk&w=def&g=0&i=BWS-16!WSV-4!SV-2!HFO-4!DRO-4!STOR-8!GW-8!WRI-4!ECOS-2!MC-4!WCG-8!ECOV-2!&tr=ind-1!prj-1&l=2&b=terrain&m=group

[3] http://twap-rivers.org/indicators/

Figure 1. The AQUEDUCT (top) and TWAP (bottom) water data web-portals



Source: WRI and UNEP, 2016.

The second product (TWAP), developed by UNEP-DHI and the other partners of the consortium, specifically focuses on transboundary basins and presents a baseline assessment for 15 indicators belonging to 5 different groups:

1. Water Quantity:
    - Environmental water stress; human water stress; agricultural water stress.
2. Water Quality:
    - Nutrient pollution; wastewater pollution.
3. Ecosystem:
    - Wetland dis-connectivity; ecosystem impacts from dams; threat to fish; extinction risk.
4. Governance:
    - Legal framework; hydro-political tensions; enabling environment.
5. Socioeconomics:

- Economic dependence on water resources; societal wellbeing; exposure to floods and droughts.

The values associated to each indicators are presented in a normalized scale ranging from 1 (Very Low) to 5 (Very High) at the transboundary river basin geographical scale (one value for each international basin). The baseline scenario represents the situation of the year 2010, while future projections are available for the years 2030 and 2050 for 5 indicators, namely: **quantity** - environmental water stress, human water stress; **quality** – nutrient pollution; **governance** – exacerbating factors of hydro-political tension; **socioeconomic** – change in population density (UNEP-DHI & UNEP 2016).

In light of the preparation for the Atlas of Water Conflict and Cooperation, the most interesting indicators in TWAP were identified among the ones belonging to the "governance" group. In particular, we refer here to the *hydro-political tensions* for the baseline scenario, and the *exacerbating factors of hydro-political tension* for the future scenarios.

Hydro-political tension in TWAP is based on the rationale that governance of transboundary basins is driven by the existence of previous treaties: for this reason, the existence of previous treaties is considered as indicator of low risk of hydro-political tensions. Moreover, the treaties should cover six legal principles, defined as follow: (a) *equitable and reasonable utilization*; (b) *not causing significant harm*; (c) *environmental protection*; (d) *cooperation and information exchange*; (e) *notification, consultation or negotiation*; (f) *consultation and peaceful settlement of disputes* (UNEP-DHI & UNEP 2016). The coverage of all the legal principles by the previous treaties is considered a factor reducing risk. The level of hydro-political risk is amplified in case of planned infrastructural development, especially if upstream and downstream countries did not specifically regulate water allocation and management. The indicator was developed following existing literature (De Stefano, Edwards, et al. 2010; De Stefano, Duncan, et al. 2010) and basing on information (Transboundary Freshwater Disputes Database - TFDD) that were initially collected for the project Basin at Risk (Yoffe et al. 2003).

The projected indicator *exacerbating factors of hydro-political tensions* is, instead, based on the combination of the occurrence of six sub-indicators (ranked in a scale low-medium-high), namely: high or increased climate-driven water variability; recent negative trends in water reserves; intra-state armed conflicts; interstate armed conflicts; recent history of unfriendly relationships over water; low gross national income per capita (UNEP-DHI & UNEP 2016).

The main limitations of this approach are represented by the coarse geographical scale that is limited to the transboundary river basin level by data availability, and by the inevitable simplification in the aggregation methodology.

2.2 Causal relations and aggregation

An accurate review of the political science and economic literature about the issues of conflict, cooperation and water scarcity was conducted by Couttenier and Soubeyran and is provided in the section 2 of the study that complements this report (**Annex 1**). For this reason, in this subsection we reported only the most important findings.

The bottom line of the literature review could be summarized in a handful of milestones characterizing the structure of the analysis presented in this report. Fearon (1995; 2005) stated that interactions between two or more parties could result in conflicts when there is no mutual advantage to reach an enforceable agreement or when the parties fail to reach such an agreement. Extensive literature analyzes the two main factors leading to conflict: capacity, defined as the ability of a country or an actor to fight; and opportunity, defined as the incentive to fight (Couttenier & Soubeyran 2015). Both capacity and opportunity suggest a relationship between climate and conflicts, directly or indirectly. In the poorest rainfed agriculture based economies, for instance, the occurrence of dry periods is likely to reduce the opportunity cost of getting involved in labor intensive fights. Burke et al. (2009), for instance, found a strong correlation between temperature and civil war episodes in Africa. Hsiang et al. (2011) found a relation between the historical civil conflicts on a global scale and the El Nino Southern Oscillation.

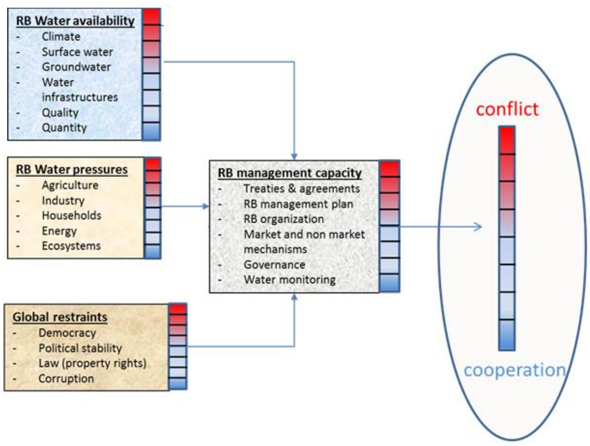
In the context of water related issues, the value at stake is enormous not only in monetary terms. This factor drove the historical crisis to be resolved most of the time with (more or less satisfactory) agreements between the parties. The occurrence of conflicts over water in the history is, in fact, a residual event and none of them reached a formal declaration of war (Yoffe et al. 2003; Yoffe et al. 2004; Kalbhenn & Bernauer 2012; Böhmelt et al. 2014). The likelihood of reaching an agreement in the context of water related issues is influenced by several factors. As summarized in Couttenier & Soubeyran (2015), the literature on international interactions between countries sharing a watershed found that the probability to reach an agreement is influenced by time-invariant (as for instance geographical and topographic characteristics), and time-varying (as for instance climatic/meteorological variables, as well as socio-economic characteristics) correlates. Quantitative analysis was used to find the causal relations leading to the formation of treaties. Zawahri & Mitchell (2011) argued that the formation of treaties is a by-product of state interest, transaction costs, and distribution of power. Dinar et al. (2011) analyzed the main reasons why some treaties are more likely to be discussed in some basins and between some riparian states respect to others. They found that scarcity and cooperation follows an inversed U-shaped curvilinear relation, in the sense that cooperation is higher when water scarcity is moderate, instead of very high or low. Extreme situations are found to be inhibiting factors. These and other studies (as for instance Beck et al. 2014; Böhmelt et al. 2014) found evidence on the influence of economic factors, trade dependency, virtual water trade, presence of water infrastructures, quality of the institutions, governance, presence of supra-national authorities, cultural background, on the bi-lateral and multi-lateral relations between the countries facing allocation, management, and pollution problems over shared water sources.

3 Methodology and data

In the light of the existing products described above and the analysis of the political science and economic literature about the issues of confrontational or cooperative international interactions, for the Atlas of Water Conflict and Cooperation it has been decided to combine the information at transboundary basin level with local scale gridded data. This in order to capture local scale dynamics that are likely to influence international relations over water at regional scale. The collected information are processed through quantitative analysis in order to highlight, first of all, the socio-economic and bio-physical factors that are more likely to influence the hydro-political tensions; second, the assessment of the causal relation-, or at least a correlation-, based estimate to assign the relative weight of each of the selected indicators. The results of the analysis are plugged in an interactive and user friendly digital web based product.

The Atlas is designed under a framework structured adopting concepts from political science and environmental economics. Three main groups of indicators are highlighted: river basin freshwater availability; human pressure on water resources; global restrains (**Figure 2**).

Figure 2. Atlas of Water Conflict and Cooperation conceptual framework



Source: JRC, A. Reynaud, 2015.

3.1 Data

One of the main limitations of the analysis presented in this report is linked to data availability. In particular, we refer to data about historical episodes of water tensions and cooperation, the most important element to determine estimates of historical causal relations, or at least correlation, with explanatory factors under specific control variables. These, in fact are characterized by coarse spatial resolution, limited to bilateral country interactions for each transboundary basins, and cover a limited amount of time. Two databases of historical water related issues are currently available: the Transboundary Freshwater Dispute Database (TFDD) developed by the Department of Geosciences of the Oregon State University (Yoffe et al. 2003; De Stefano, Edwards, et al. 2010), providing information about international water basin agreements between 1816 and 2007. The second product is the International River Cooperation and Conflict database (IRCC), providing information about water related issues between countries sharing watersheds between 1997 and 2007 (Kalbhenn & Bernauer 2012). Each water related episode recorded in the database is labeled in base of a scale assigning a score (**Table 1**) representing the intensity of the issue, and its direction (+6 most cooperative, -6 most confrontational).

Table 1. IRCC event score scale and occurrences.

Score	Type	Occurrences	Frequency %
6	alliance	2	0.03
5	official support	8	0.14
4	agreement/commitment	819	13.93
3	agreement of low scale	1,271	21.61
2	verbal support	1,092	18.57
1	minor official exchanges, talks or policy expressions	1,075	18.28
0	neutral acts	690	11.73
-1	mild verbal expressions displaying discord in interaction	594	10.10
-2	strong verbal expressions displaying hostility in interaction	253	4.30
-3	hostile actions	50	0.85
-4	breaking diplomatic relations	19	0.32
-5	any violent acts (that do not yet constitute a war)	8	0.14
-6	Violent conflict, formal declaration of war	0	0.00

Source: Kalbhenn & Bernauer 2012

Beside the scarce temporal coverage (11 years) and the limited number of events, an additional limitation of the use of this database is the uneven geographical distribution of the observations. About 4,800 of the 10,272 observed events come from the 10 most represented international river basins, majority of those from the Danube and Nile River Basins (Kalbhenn & Bernauer 2012). Although this database is far from being an optimal solution for the analysis, it is the one that presents the largest coverage of events, that for, it was chosen for this study.

Regarding climate stressors and water stress, we used data developed internally by the JRC. In the first formulation of the analysis (**Annex 1**), two water stress indicators (Water Dependency Index –WDI- and Falkenmark Index) were used. Even though these indexes are widely used to express the water stress as over-withdrawal respect to the physical availability (WDI) and per capita water availability (Falkenmark), they incorporate elements of water demand, strongly correlated with socio-economic conditions. This feature caused a bias in the analysis affecting the conclusion of the first version of the study (see the concluding section of **Annex 1**).

In this updated version of the analysis we integrated the biophysical information using highly spatially detailed climate data derived from the Multi-Source Weighted-Ensemble Precipitation (MSWEP) database (Beck et al. 2016). Using this database, we calculated a water stress indicator based only on variation in the temporal distribution of precipitation: the Standardized Precipitation Index (SPI) (McKee et al. 1993). This climate proxy is widely used for drought quantification and monitoring. The index is a measure expressed in standard deviation units of the variation of the precipitation of a specific number of month respect to the long run average (WMO 2012). The number of month basing on which the SPI could be calculated usually varies between 3 and 48 months. A "shorter" SPI (3 months) is usually utilized to detect meteorological droughts; a relatively "longer" SPI (6-12 months) is usually associated with agricultural droughts; a "longer" SPI (24-48 months) is associated with hydrological droughts. It was calculated using the R package SPEI (Beguería & Vicente-Serrano 2014).

Socio-economic data were taken from widely used databases. In particular, we used:

- Per capita Gross Domestic Product (Gleditsch 2002);
- Institutional quality – derived from the from the International Country Risk Guide (ICRG) ([4]);

[4] https://www.prsgroup.com/about-us/our-two-methodologies/icrg

- Polity score - autocracy/democracy come from Polity IV project dataset (Marshall & Cole 2014);
- Agriculture (% GDP) and Rural population (% of the total) – derived from the World Development Indicator database (World Bank n.d.)

3.2 Quantitative analysis

In the first formulation of the study (**Annex 1**), different versions of a statistical model were tested to explain separately the probability of conflict and cooperation. The chosen model is a linear panel regression considering country-dyad/basin and time fixed effect (FE). The unit of analysis is country i x country j x basin b.

In the first step, the cooperation or confrontational events are analyzed as function of bio-physical factors. The resulting model is structured as follow (***Eq. 1***):

Eq. 1

$$Event_{ijbt} = \alpha WaterStress_{bt} + FE_{ijb} + FE_t + \varepsilon_{ijbt}$$

Where:

$Event$ represents the number of conflict or confrontational events for the specific dyad of countries in the specific international basin at time t. $WaterStress$ represents the set of climate stressors: in the first formulation of the analysis these included WDI and Falkenmark index, jointly with average precipitation and temperature; in this new formulation, $WaterStress$ is represented by SPI and the climate variables derived from the MSWEP database.

In the second step, country specific control variables are included (***Eq. 2***):

Eq. 2

$$Event_{ijbt} = \alpha WaterStress_{bt} + X_{ijt}\beta' + FE_{ijb} + FE_t + \varepsilon_{ijbt}$$

Being X the vector of the time varying country specific socio-economic variables: per capita GDP, share of the GDP produced by the agricultural sector (economics); Share of rural population (demographic); institution quality, and level of democracy (governance).

In a third step, the model was developed to test the heterogeneous effect of the combination of climatic and socio-economic variables (***Eq. 3***):

Eq. 3

$$Event_{ijbt} = \alpha WaterStress_{bt} + X_{ijt}\beta' + WaterStress_{bt}\, x\, X_{ijt}\gamma' + FE_{ijb} + FE_t + \varepsilon_{ijbt}$$

Being $WaterStress_{bt}\, x\, X_{ijt}\gamma'$ the interaction between the basin specific water stress and the time varying confounding factors.

This methodology allowed to draft some preliminary conclusions on the linear correlation between changes in water stress and occurrence of confrontational or cooperation events in transboundary river basins. However, the methodology adopted for the first formulation of the analysis did not manage to fully capture the dynamics involved in the complex phenomenon under consideration. The involved relations, in fact, are not always linear, and the heterogeneous effects are not fully captured with the approach formulated the model described by ***Eq. 3***. For this reason, in the present formulation of the analysis, we tested the curvilinear (quadratic) relations between hydro-political issues (***Eq. 4***).

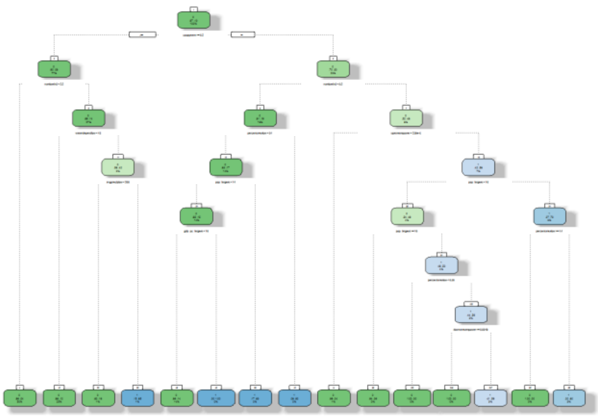
Eq. 4

$$Event_{ijbt} = \alpha WaterStress_{bt} + X_{ijt}\beta' + X_{ijt}^{2}\beta' + FE_{ijb} + FE_t + \varepsilon_{ijbt}$$

Being X the vector of the time varying country specific socio-economic variables: per capita GDP, share of the GDP produced by the agricultural sector (economics); Share of rural population (demographic); institution quality, and level of democracy (governance), as described for ***Eq. 2***.

The successful application of the test, brought us to explore the possibility to use a machine learning derived tool, to quantitatively assess the linear and non-linear relations between the hydro-political events recorded and the time-varying and time-invariant biophysical and socio-economic explanatory variables. The selected tool, Random decision Forests, is based on the decision trees learning approach popular for non-linear multi-variate classification and regression (Tin Kam Ho 1998; Breiman 2001). Random Forests involve an ensemble of regression trees calculated on random subset of data that are split randomly in base of specific features of each of the independent variables (**Figure 3**) (Strobl et al. 2009; Welling et al. 2016; Liaw & Wiener 2002).

Figure 3. Schematic representation of a Random Forests tree.



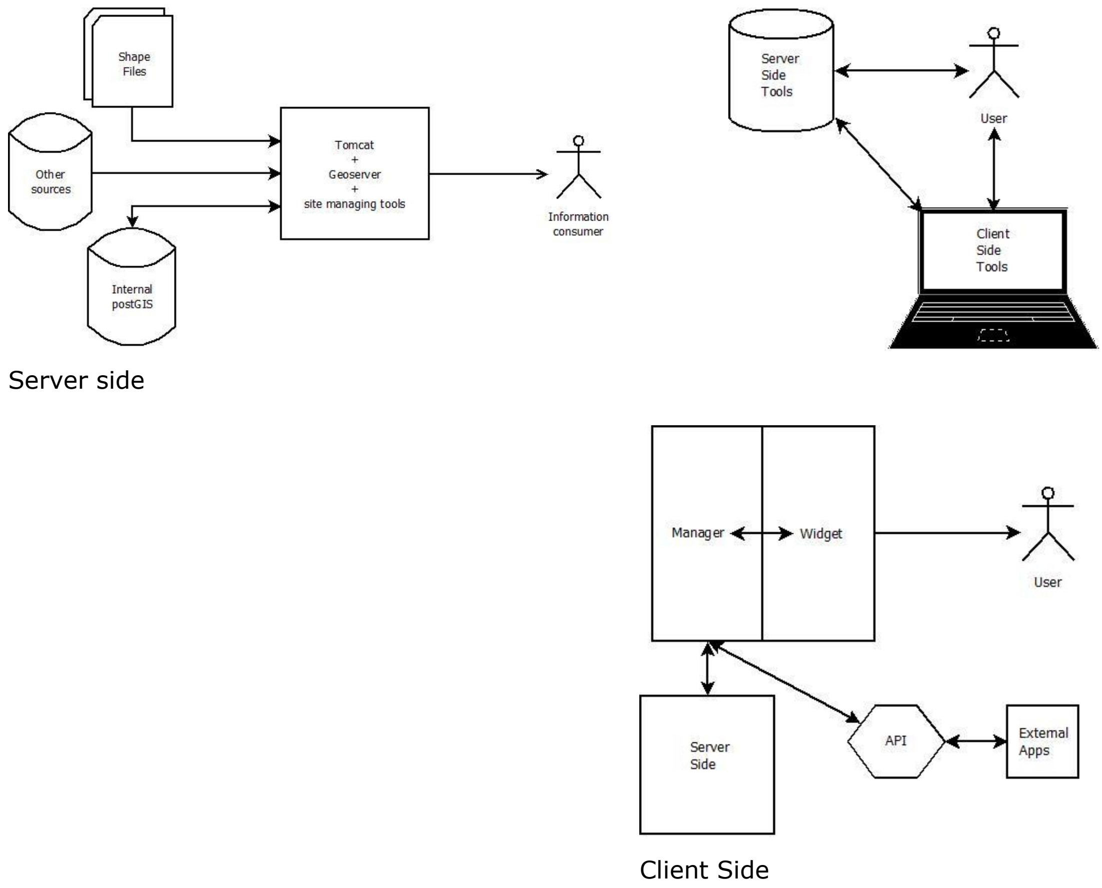
3.3 Graphical tool technical specifications

The online tool developed makes available the geographic data brought by the project, as well as utilities to display data and perform calculations and manipulations over them. To fulfill these purposes, a set of tools is proposed, based on a server/client structure: a geoServer to maintain the geographic data and making them available, a PostGIS database to store geodata, and a client web-based tool designed to display and manipulate those data.

In order to make the information accessible to the public in general and to the geographic tools specifically, it is necessary to implement a publishing service methodology. In the proposed structure these aims are reached through a geoServer instance (running on a Tomcat server), which allows the publication of the data layers stored in a postGIS database, and also allows the access to some sets of data contained in shapefiles. The geoServer works in combination with other tools for site management, rendering and some secondary functionalities.

The advantages of a geoServer are mainly represented by low cost and available documentation. Since it is an open source tool, there are no licensing costs associated. Moreover, it is one of the most popular geographic servers, that for, there is a large amount of documentation and previous experiences facilitating the implementation process.

Figure 4. Atlas of Water Conflict and Cooperation graphical tool architecture



Source: JRC, D. Gonzalez Sanchez, 2016.

Upon the geoServer platform, information coming from different sources is integrated, such as shape files and other external sources that are integrated in the methodology. The geoServer is backed with a PostgreSQL/PostGIS database to store and process the geodata.

On the server side, the tool proposed is a reusable component, programmed with Javascript and several geographic libraries that can be incorporated in any website that might need a geographic component with the functionality of the Atlas.

The proposed approach focus on the idea of a modular and incremental component, made up of different modules, each one of them in charge of some particular feature or functionality. The functionalities developed consist of two different parts, one managing aspect, and a Widget that implements all the features related to the user interface and graphic works.

With this perspective, the different components that are implemented could correspond to the following categories:

- Map - the graphic element which allows the display of basemaps and layers;
- Map controls - the functional elements allowing to take control of the actions to be performed by the map element (zoom, overview, scale, legend…)
- Operation widgets - functional element that allow interactions with the geographic information displayed on the map, and performing some operations over it. Within these operational widgets will be found, among others:
    - Layers panels: this component allows to interact with the biophysical variables to display, and performs some simple operations such as show/hide the information, recover data at some extent/point, selection criteria, time evolution, and so on.
    - Charting tools: this component allow to display the information in a comprehensive appearance using graphic tools;
- Data manager - element needed to recovery and store the information, to interact with servers. This data manager could divide its functions between a real data manager (that takes care of the interaction with external sources) and a layer management, that manages the data once recovered from external sources;
- API - a handful interface that can be used by the web application to communicate with the geographic component.

The main advantages of this approach could be summarized as follow:

- Reusability - the component can be easily incorporated to any web application;
- Extensibility - the component can expand its functionalities by the addition of new modules;
- Adaptability - the component can deploy a whole set of functionalities or a restricted one depending on the initial configuration;
- API - the inclusion of an API allows an easy way to interact with external features of the website where it is placed.

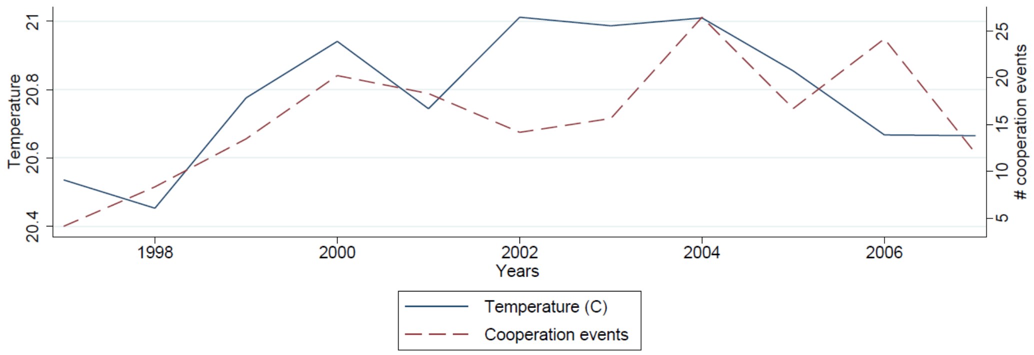
4 Results

4.1 Statistical relations

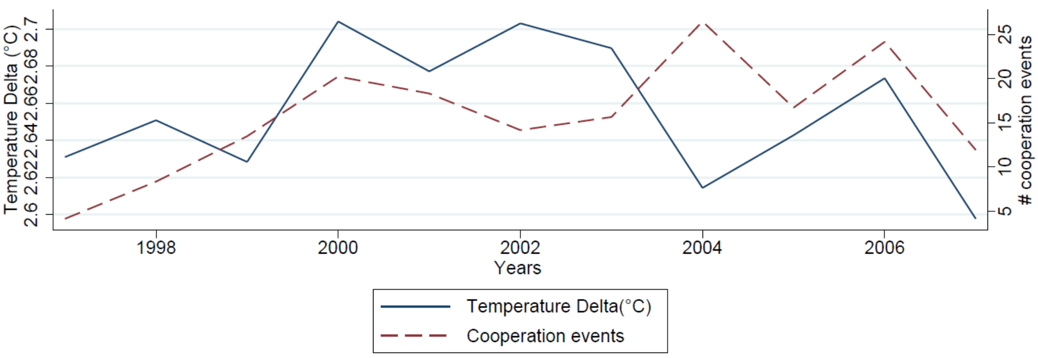
The first formulation of this study (**Annex 1**), found significant linear relations between water stress proxies and cooperation between countries in international basins over water related issues. It failed, however, to find a relation for the confrontational hydro-political events. The proxies utilized to represent water based stressors in the analysis, the Water Dependency (WDI) and Falkenmark indexes, were found significant in some cases, but in general they were found not fully satisfactory. Both the indicators, in fact, are calculated incorporating anthropogenic water use, that for, endogenous to hydro-political issues.

In this new formulation, using more detailed climate data and water stress indicators based on the precipitation data, we aimed at overcoming the limitations of the initial formulation of the study. The use of the Standardized Precipitation Index (SPI) and the spatially detailed temperature data managed to slightly improve the significance of the factors correlated with both cooperation and confrontational events. In **Figure 5** and **Figure 6**, the evolution of the main climate variables and hydro-political cooperation and confrontational events are presented.

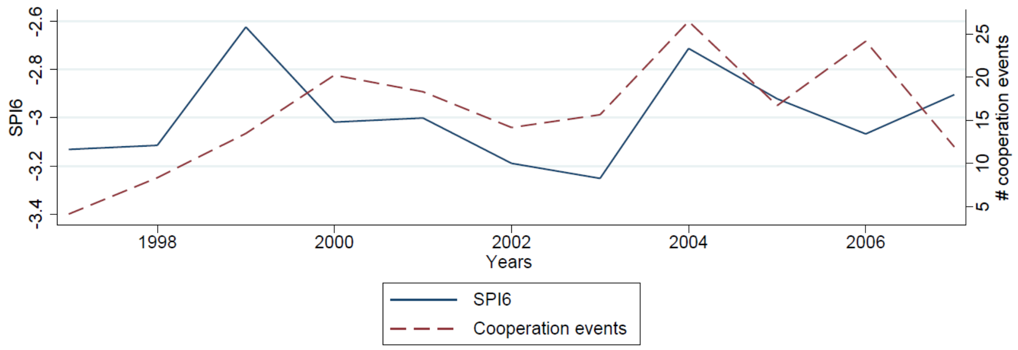
Figure 5. Evolution of temperature (a), temperature delta (b) between the countries involved, and SPI6 (c) variables and cooperation events



(a)

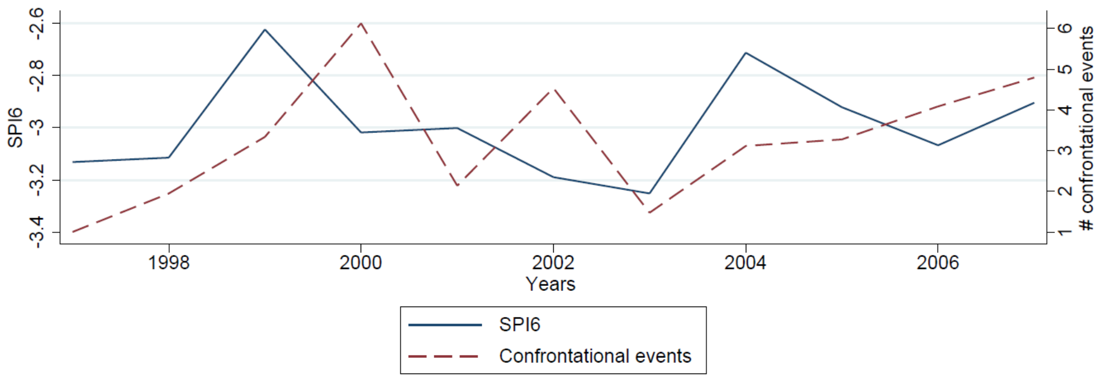


(b)

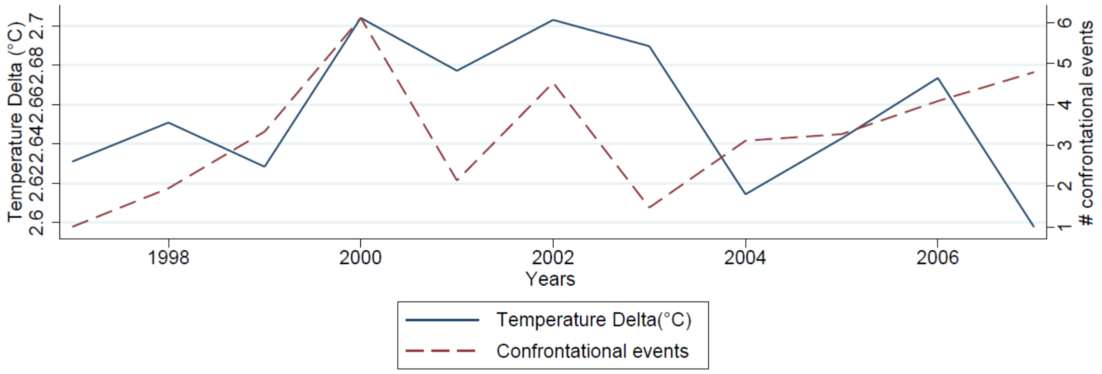


(c)

Figure 6. Evolution of SPI6 (a) and temperature delta (b) variables and confrontational events



(a)



(b)

Both confrontational and cooperative hydro-political events, were found to be positively correlated to 6 month standard precipitation index (SPI6), temperature, and temperature difference between the countries involved in the event.

Results of the statistical analysis with the MSWEP data considering only climate stressors are presented in **Table 2** (cooperative hydro-political events) and **Table 3** (confrontational hydro-political events).

Table 2. Results of cooperation events analysis with model associated to Eq. 1.

	(1)	(2)	(3)	(4)	(5)
VARIABLES	cooperation	cooperation	cooperation	cooperation	cooperation
MSWEP Temperature	-1.67**				
	(0.65)				
Delta Temperature between country 1 and country 2		-2.55***			
		(0.80)			
MSWEP Precipitation			0.00		
			(0.00)		
SPI 6 months				0.96***	
				(0.26)	
SPI 12 months					0.63***
					(0.24)
Observations	10,272	10,236	10,272	10,272	10,272
Adjusted R-squared	0.46	0.46	0.46	0.46	0.46
Bilateral fixed effects	1	1	1	1	1
Year Fixed effects	1	1	1	1	1

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 3. Results of conflictual events analysis with model associated to Eq. 1.

	(1)	(2)	(3)	(4)	(5)
VARIABLES	conflict	conflict	conflict	conflict	conflict
MSWEP Temperature	-0.10				
	(0.14)				
Delta Temperature between country 1 and country 2		-0.80***			
		(0.26)			
MSWEP Precipitation			0.00		
			(0.00)		
SPI 6 months				0.02	
				(0.08)	
SPI 12 months					0.08
					(0.08)
Observations	9,159	9,123	9,159	9,159	9,159
Adjusted R-squared	0.25	0. 25	0. 25	0. 25	0. 25
Bilateral fixed effects	1	1	1	1	1
Year Fixed effects	1	1	1	1	1

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

The results presented in in **Table 2** are in line with the findings of the original formulation of the study. All the climatic stressors analyzed, with the exclusion of total precipitations, are found to be significant with cooperative hydro-political events. In particular, temperature and temperature difference between the countries involved in the issues are expected to negatively impact the likelihood of having cooperation. Cooperation is more likely to happen in reduced water stress conditions (corresponding to higher SPI6 and SPI12 values). The significance of the biophysical variables, except for the temperature difference and SPI12, holds when also the country specific socio-economic control variables are taken into account in the analysis (**Table 4**). The interaction between the biophysical and socio-economic variables, however, is affected by the endogeneity of climate factors in the economic dynamics, especially in the poorest countries.

Regarding the confrontational events, as shown in **Table 3**, temperature difference was found to be significant, improving the results of the original formulation of the study (**Annex 1**), where no significant relations were found. In particular, increasing temperature variation, was found to be negatively correlated with the confrontational hydro-political events. It has to be noted, however that the scarce number of events recorded are very likely to bias the results here presented.

Table 4. Results of cooperation events analysis with model associated to Eq. 3. Country specific controls

	(1)	(2)	(3)	(4)
VARIABLES	nb_cooperation	nb_cooperation	nb_cooperation	nb_cooperation
MSWEP Temperature	1.96**			
	(0.93)			
Delta Temperature between country 1 and country 2		-1.14		
		(0.96)		
SPI 6 months			0.98***	
			(0.30)	
SPI 12 months				0.29
				(0.34)
GDP/per cap	-9.84**	-9.58**	-9.76**	-9.60**
	(4.40)	(4.41)	(4.36)	(4.41)
Institutional quality	15.76	15.96	15.19	15.40
	(12.65)	(12.65)	(12.57)	(12.66)
Polity score	0.50	0.47	0.47	0.47
	(0.39)	(0.40)	(0.39)	(0.40)
Oil/Gas, net exporter	0.38	0.68	0.90	0.61
	(6.11)	(6.12)	(6.09)	(6.10)
Agriculture (\% GDP)	-0.98***	-0.97***	-0.96***	-0.96***
	(0.29)	(0.29)	(0.29)	(0.29)
Rural population (\%)	0.50	0.55	0.55	0.56
	(0.54)	(0.54)	(0.54)	(0.55)
Observations	6,451	6,451	6,451	6,451
Adjusted R-squared	0.49	0.49	0.49	0.49
Bilateral fixed effects	1	1	1	1
Year Fixed effects	1	1	1	1

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Although the new findings could give an idea of the linear relations between climate stressors and hydro-political events, the factors influencing the dynamics involving water related issues are extremely complex and very unlikely to be captured by linear models.

As in the original formulation of the study (**Annex 1**), we found extremely interesting the analysis of the heterogeneous effects of biophysical and socio-economic variables. In particular, we tested the heterogeneous effects of the Standardized Precipitation Index and we found that the impact of this variable is extremely different in countries characterized by different levels of GDP, level of institutional development, and importance of agriculture in the national economy. Moreover, the effect of an increased water stress on the likelihood of cooperation is higher if the affected country is downstream respect to the counterpart.

The complexity of these interactions, brought us to test the curvilinear (quadratic) relations between the selected explanatory variables and the hydro-political events (**Table 5**).

Table 5. Results of cooperation events analysis with model associated to Eq. 4. Curvilinear relations

VARIABLES	nb_cooperation
SPI 6 months	0.96***
	(0.30)
GDP/per cap	31.80
	(20.53)
Squared GDP/per cap	-2.32*
	(1.30)
Institutional quality	-12.83
	(35.58)
Squared Institutional quality	24.42
	(30.04)
Polity score	-0.05
	(0.41)
Squared Polity score	-0.12**
	(0.05)
Oil/Gas, net exporter	-1.43
	(5.58)
Agriculture (\% GDP)	0.53
	(0.55)
Squared Agriculture	-0.02**
	(0.01)
Rural population (\%)	4.91***
	(1.11)
Squared Rural population	-0.03***
	(0.01)
Observations	6,451
Adjusted R-squared	0.49
Bilateral fixed effects	1
Year Fixed effects	1

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

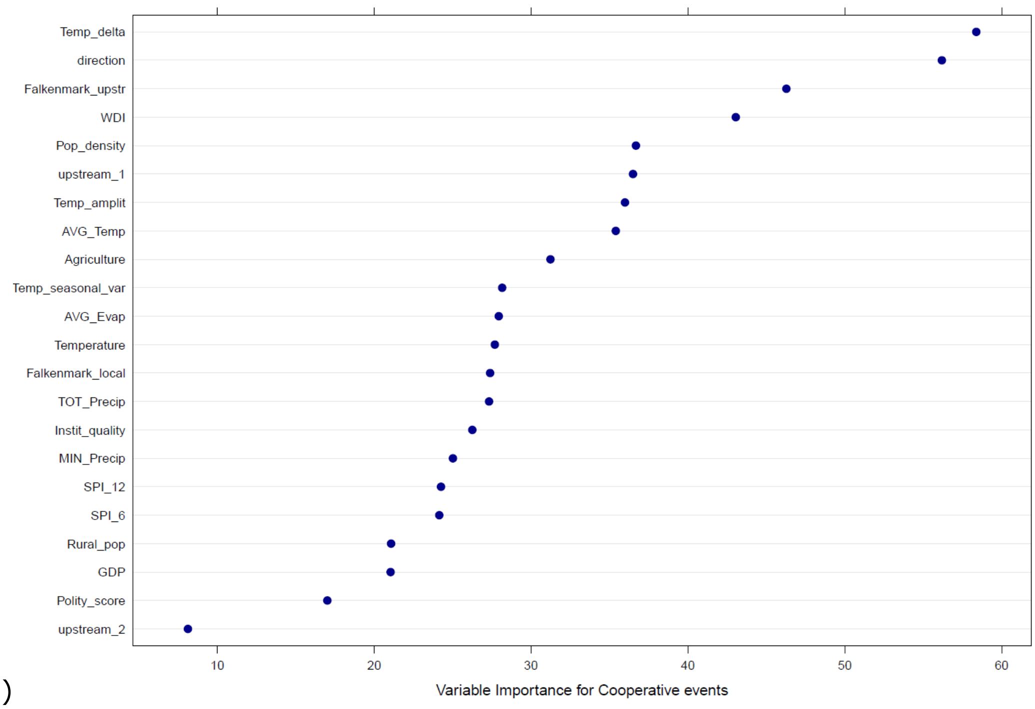
As expected, the results of the test (**Table 5**) show that many quadratic variables are found to have significant relation with the hydro-political events (in this case cooperative).

The results described suggested that the use of different model could be beneficial to describe the curvilinear relation. For this reason, as described in the methodology, we decided to perform a Random Forests analysis. In particular we set up three different models aimed at estimating the importance of the factors influencing:

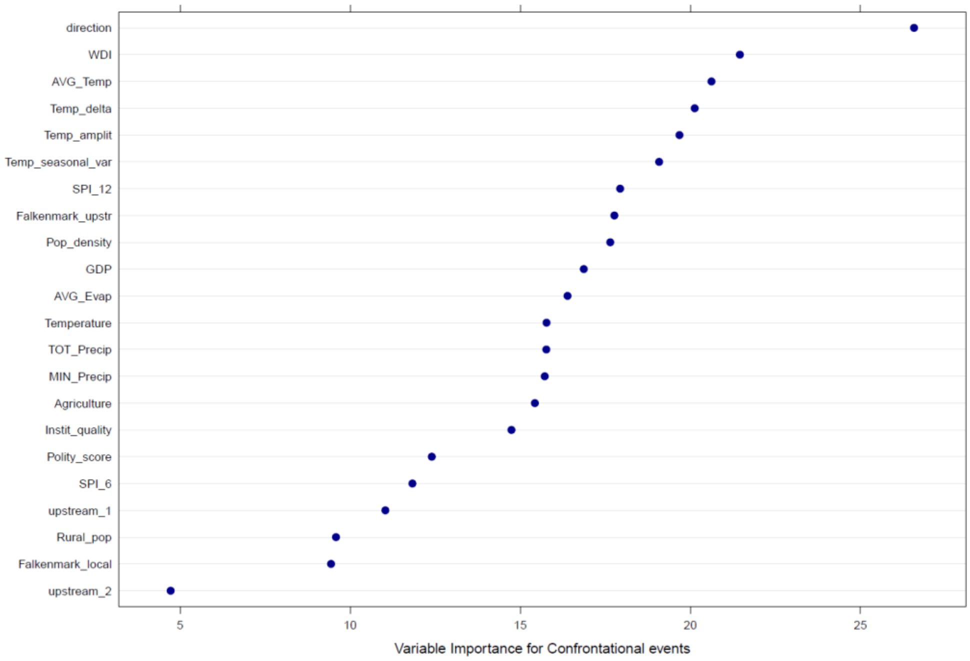
- RF1: Occurrence of cooperative hydro-political events;
- RF2: Occurrence of confrontational hydro-political events;
- RF3: Intensity of the events (IRCC score in **Table 1**).

Random forests analyses highlight the importance of each of the independent variables taken into consideration in explaining the variance of the dependent variable considering the ensemble of the interactions created in each of the randomly determined trees. In **Figure 7** the results for each of the three (RF1 to RF3) analyses are presented. One of the advantages of this approach respect to the fixed effect model used before, is that also time invariant characteristics of the country/basin/year combination, as for instance the geographical characteristics, could be taken into consideration. The flow direction, in fact, is one of the variables that are found to be more influential jointly with climate stressors and socio-economic factors. This is in line with the findings described above, where the heterogeneous effect of the SPI 6 on the likelihood of cooperative hydro-political events was found dependent on the relative geographical position (upstream/downstream) of the two countries involved.

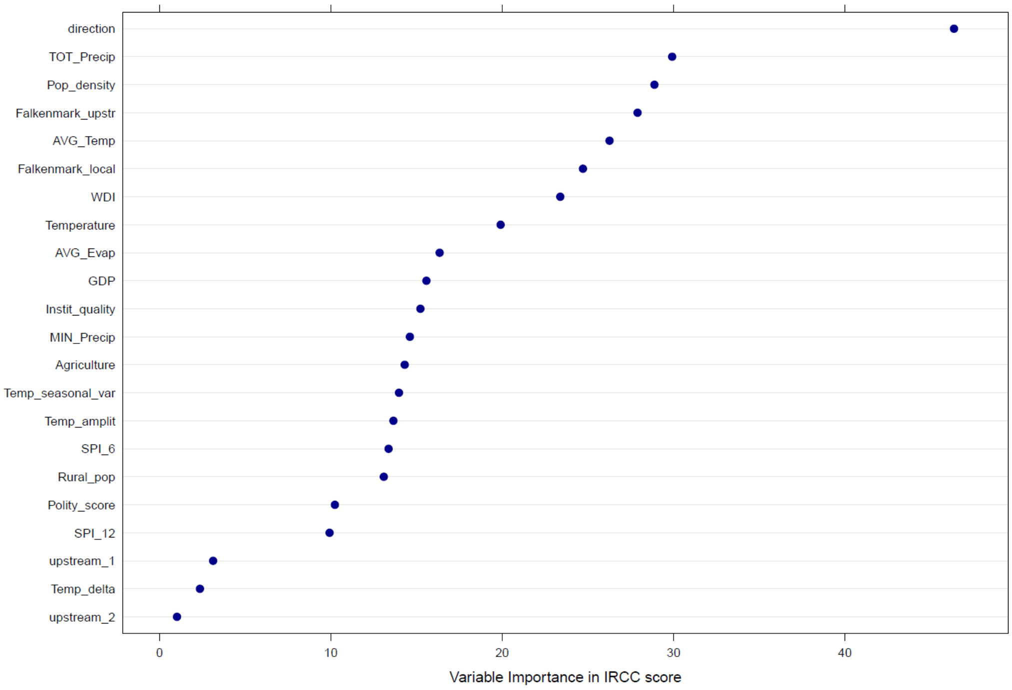
Figure 7. Variable importance plots: (a) RF1, (b) RF2, (c) RF3.



(a)



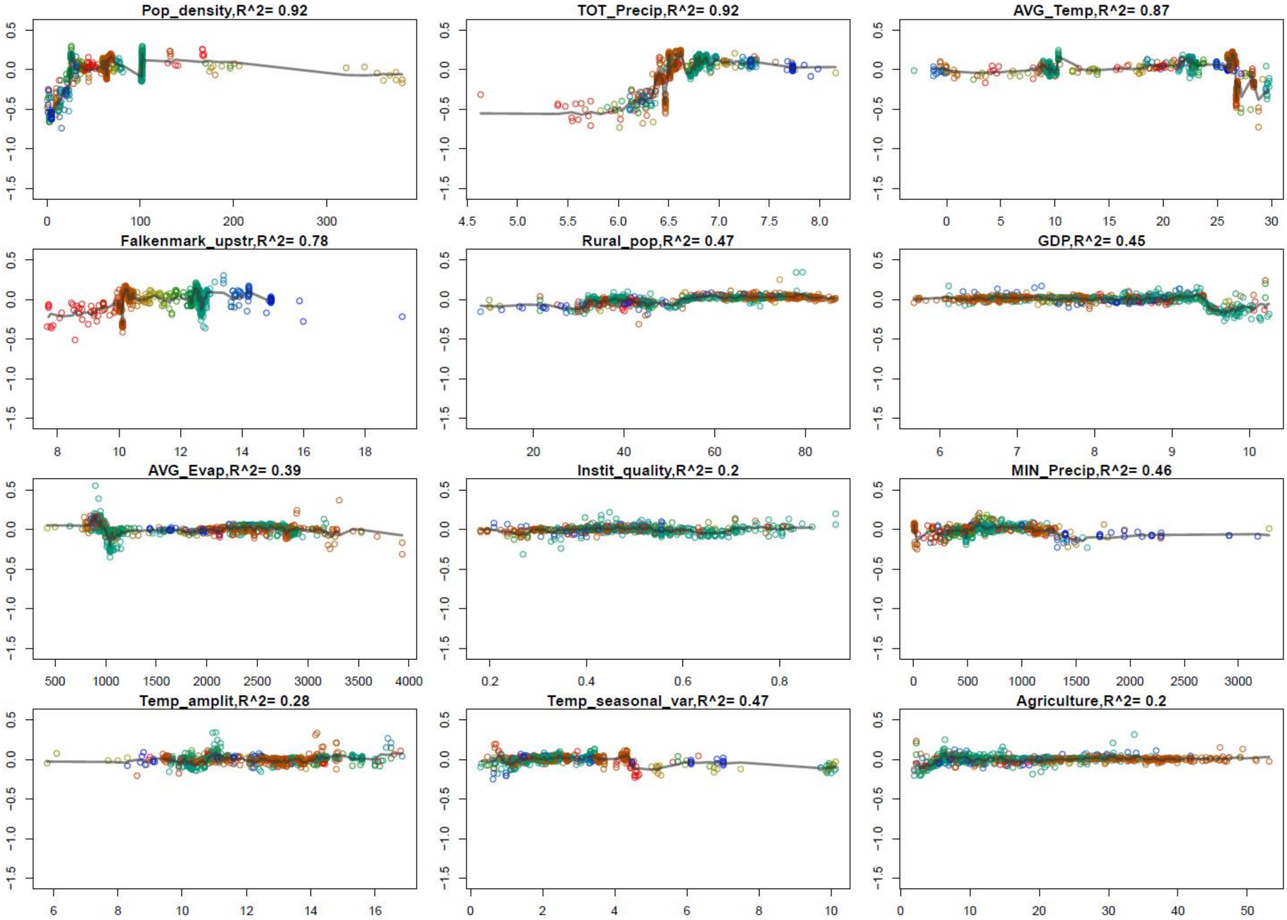
(b)



(c)

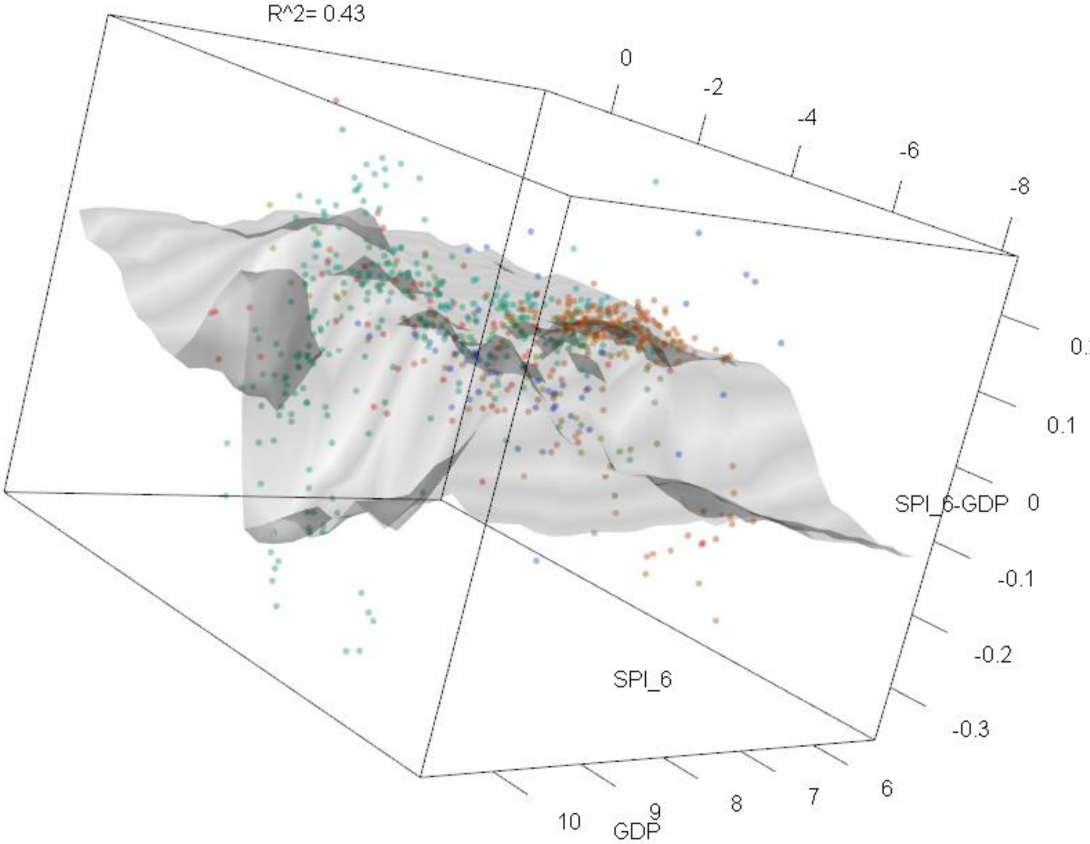
Another important aspect of the Random Forests approach is that it facilitates the analysis of the interactions between the most important variables and their relative impact on the dependent variable (respectively colors and lines in **Figure 8**). Here, for instance, it is possible to highlight that the low income countries (red dots in **Figure 8**) that have the highest share of agriculture and rural population, are more affected by high temperature amplitude and low Falkenmark index. Their likelihood to cooperate over hydropolitical issues depends on the combinations of all the variables.

Figure 8. Relative importance (grey lines) of a selection of variables in determining the IRCC score (RF3 analysis), and their mutual interactions (colors).



In this way the analysis of the non-linear relations is facilitated as shown in **Figure 9**. Here, for instance, it is possible to highlight how low, middle, and high income countries are found to behave differently in case of increasing water stress.

Figure 9. Non-linear relations between 6 months Standard Precipitation Index and GDP in determining the IRCC score (RF3).



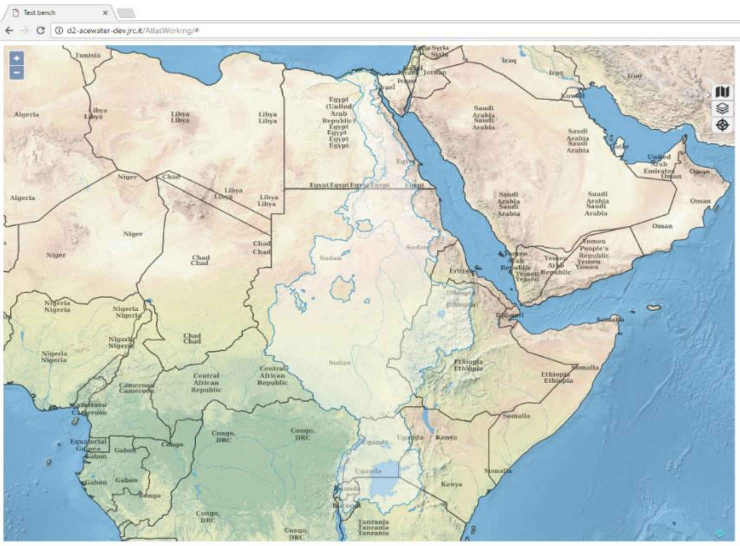
4.2 Graphic output

The designed graphical tool is organized to interactively display:

- Maps (base-maps and layers) & Map controls (zoom, overview, scale, legend, etc);
- Functional element that allow interacting with the geographic information displayed on the map, and performing some operations over it (operation widgets; layers panels; charting tools);
- Tools aimed at managing and temporarily store the information displayed and the combinations created by the user (Data Manager).

The instrument is designed to be extremely flexible and user friendly. The information is visualized at the river basin level or at raster level when available (example of the Nile basin in **Figure 10**).

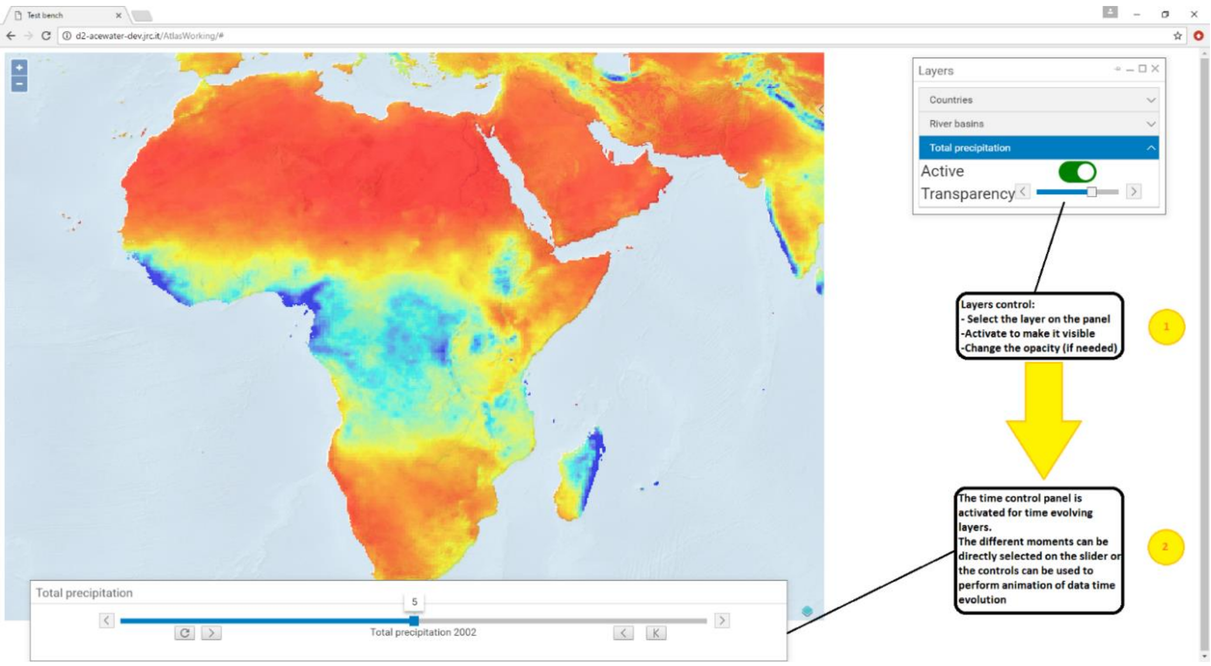
Figure 10. Beta version of the Atlas of Water Conflict and Cooperation: visualization of data at river basin/country level.



Source: JRC, D. Gonzalez Sanchez, 2016.

Data about biophysical and socio-economic variables are displayed as either raster or vectorial layers. The result is a collection of data time series with the data sampled at a certain resolution. The tool provides the controls necessary to display the data, taking into account also their temporal evolution (**Figure 11**).

Figure 11. Beta version of the Atlas of Water Conflict and Cooperation: data visualization (control 1), with highly detailed spatial and temporal evolution (control 2).



Source: JRC, D. Gonzalez Sanchez, 2016.

5 Conclusion and future research

This report introduces the Atlas of Water Conflict and Cooperation, a tool designed to assist policy makers in coping with potential hydro-political risk in shared watersheds by monitoring the factors that are found to be influential for the evolution of historical cooperational or confrontational events.

The idea was to use quantitative analysis to empirically identify the variables that are more relevant for water related issues, and estimate the relative weight of each of the variables. The first formulation of the analysis (the one described in **Annex 1**), was designed using linear models to study statistical correlations between the factors influencing hydro-political events. The main results of the original formulation of the quantitative analysis found significant relations between water stress indicators and temperature with cooperation events, but failed to find correlations with confrontational episodes. One of the main limitation highlighted was represented by the water stress indicators incorporating water demand estimates, highly correlated with socio-economic control variables.

The updated analysis, presented in this report, uses more spatially detailed climatic data and water stress indicators calculated basing on the only precipitation variability (the Standardized Precipitation Index), and studied the non-linear relations between socio-economic and biophysical factors and hydro-political events. Starting from the original methodology, this analysis succeeded in improving the results of the previous formulation. However, the study, as it was designed, suffered for the limitations imposed by the lack of more spatially detailed data about historical water related issues, and by the ineffectiveness of linear statistical models in capturing non-linear relations.

The second set of limitations were overcome by analyzing the curvilinear relations and testing their significance. Once the curvilinear relations were found to be significant, the quantitative analysis was restructured using a tool derived from machine learning (Random Forests). The new analysis managed to identify the factors most influential in determining transboundary hydro-political issues, and contributed to quantify the relative importance of each of the factors.

The findings of the quantitative analysis were used as basis for a web based interactive tool aimed at monitoring the dynamics that are likely to influence hydro-political issues.

The machine learning derived approach proved to be extremely promising for this kind of analyses: testing other machine learning based approaches, as for instance the Bayesian Network or the Dynamic Bayesian Network (DBN), could further improve the findings described in this report.

Further research at basin level scale is needed to overcome the other set of limitations: the one represented by the lack of highly detailed spatial information about water related issues. The described global approach, in fact, fails to capture the local dynamics that are likely to influence water allocation at local scale and are likely to boost cooperative or confrontational events within the countries and their social and economic structure. A basin scale approach, considering specific socio-economic and biophysical features could provide a more detailed scenario of the factors likely to exacerbate water issues in the most risky areas.

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Annexes

Annex 1. Cooperation and conflicts in international river basins: an overview

Cooperation and Conflict in International River Basins: An Overview

Mathieu COUTTENIER* Raphael SOUBEYRAN†

First version: November 2015
This version: December 17, 2015

Abstract. We study the effect of water stress on cooperation and conflict between countries sharing international river basins. We use weather measures as well as novel data on prominent indices of water stress for the exhaustive set of international river basins in the world over the 1997-2007 period. In light of the results on climate and violence found in the literature, one may expect that water stress increases conflict and decreases cooperation. In light of the literature on inter-state conflicts and cooperation, one may expect cooperation rather than conflict between dependent countries. Our main results tend to favor the latter expectation and suggest that more water stress is associated with more cooperation. We find that increases in temperature, temperature amplitude or in the water stress indices are associated with more cooperation within country pair-basins units. However, we fail to find a significant effect of any weather or water stress index on conflict. We go further and show that the average estimates hide some heterogeneity. The effect of temperature is the largest in Africa and is also large in Latin America. The effect of precipitation is very heterogenous and depends on local conditions.

JEL classification: D74, Q25, Q34, Q54, C23
Keywords: Cooperation, Conflict, Water, International, River Basin

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1 Introduction

The aim of this paper is to assess to what extent conflict or cooperation events over international river basins are related to water stress. After an intensive work of data collection, we develop an empirical model of cooperation and conflict to estimate whether water stress is associated with conflict and cooperation.

Our main results can be summarized in four main points:

1. Countries tend to cooperate more when water stress increases. The effects are sizeable. This is consistent with the fact that we focus on international river basins. Indeed, countries which share river basin depend from each other and they are then more prone to cooperate when water becomes scarce.

2. We fail to find a significant effect of water stress on conflict.

3. The effect of water stress on cooperation events depends on the local economic, demographic and political conditions.

4. The magnitude of the effect of water stress on cooperation is different across regions of the World.

The remainder of the paper is structured as follows. Section 2 proposes an overview of the literature on climate and conflict and on international river basins, conflict and cooperation. Section 3 describes our data. Section 4 presents our empirical strategy. Our results are presented in Section 5. Section 6 concludes.

2 Literature Review

The present literature is build on our recent survey of the literature on civil conflicts (Couttenier and Soubeyran, 2015), the literature review included in (Fearnehough and Reynaud, 2013) on cooperation and conflict in international river basins and the most recent academic publications on this topic.

We first review rational theories of conflict developed in political science and economics. We then review the empirical literature on conflict, cooperation and water scarcity. We start with the literature that deals with the national scale and then turn to the literature that focuses on the international scale. The literature that focuses on the national scale addresses the issue of civil conflict (and not cooperation, for which, to our knowledge no national measure has ever been proposed). The literature that focuses on the international scale analyzes both conflict and cooperation.

2.1 The Theory of Conflict

In this Section, we first briefly review the main theories of conflict. Our discussion echoes and complements existing surveys on the theoretical literature of conflict (Fearon, 1995; Garfinkel and Skaperdas, 2007; Bloch, 2009; Jackson and Morelli, 2011).

One of the main goals of the theoretical models of conflict is to explore the rational causes of conflict. There are two prerequisites for conflict between rational agents. Conflict arises only if there is no mutually advantageous and enforceable agreement or if the agents are not able to reach such an agreement (Fearon, 1995, 2005).[1] Hence, bargaining failures and situations where the benefits from conflict are greater than the costs (for at least one of the agents involved) are the causes of conflict. Reconciling rationality and conflict is challenging because a conflict implies the destruction of productive resources.[2] However, "capacity" and "opportunity" sometimes lead to conflict. Parties can be able or not to fight (they can be strong or weak, and they can be able or not to raise revenue) and they can be able or not to commit to not fighting, which are examples of what we refer to as "capacity". Parties may also or not have incentives to fight, i.e. their benefits to fight may outweigh or not their (opportunity) cost of fighting, which is what we refer to as "opportunity".

Commitment problems are pervasive causes of conflicts. An inability to enforce a bargaining agreement and/or to credibly commit to abiding by an agreement is related to the capacity of the parties to fight and their capacity not to fight. The anarchic state of nature described in Hobbes's Leviathan (Hobbes, 1651) relates to conflicts due to the inability of men to trust each other.[3] Conflict arises when the agents cannot commit to not fighting even after a transfer of resource from one agent to another (see Sonin and Schwarz (2008) for a dynamic solution to this problem). Contest models in line with Haavelmo (1954) rely on a lawless framework and on the commitment explanation of conflicts. In this literature, conflicts are predominant because of a focus on social dilemma games. A key element of these models is the technology for fighting (Hirshleifer, 1989; Grossman, 1991; Skaperdas, 1992). These models of conflict consider the trade-off between production and appropriation[4] and predict that resources devoted to a conflict should increase with the relative effectiveness of the fighting technology. This technology is broadly defined in the literature as the strategies to take power in a State. It includes different kinds of protest such as rapid strikes, public protests or revolution; different strategies to dismiss the government such as mass popular demonstrations or creating defections within the regime. The technology for fighting is also the capacity to have an access to firearms, to have skilled and trained fighters, and to have foreign support for instance. Some specific geographical conditions such as the ruggedness of the terrain, the proportion of the country that is made up of mountains, swamps or jungle may be included in the broad definition of technology.

The other causes of conflict lie in the opportunities for the different parties, i.e. their individual costs and benefits to fight: parties may fight because of asymmetric information about the potential costs and benefits of a conflict, because of the indivisibility of resources that might change hands in a war (so that not all potentially mutually beneficial bargaining agreements are feasible), because of agency problems, where the incentives of leaders differ from those of the populations that they represent, or because of multilateral interactions where every potential

[1] Jackson and Morelli (2011) update Fearon (1995)'s review and distinguish five main causes for these situations that we choose to group into "capacity" and "opportunity" causes of conflict.

[2] Garfinkel and Skaperdas (2007) claim that the challenge comes from the emphasis put by economics on the gains from trade. Starting from a conflicting situation, it is generally assumed that Pareto improvements are possible. It is difficult to rationalize behaviors that prevent these improvements.

[3] See Rohner et al. (2013b) for a theoretical model and Rohner et al. (2013a) for an empirical study in Uganda.

[4] Garfinkel and Skaperdas (2007) review the literature based on the "contest model" where the efforts put forth by the parties translate into a probability of winning a "prize".

agreement is blocked by some coalition of States or constituencies which can derail it. Distorted benefits because of information asymmetries are pervasive.[5] A lack of information about the (endogenous) strength of the adversary can also generate conflict (Meirowitz and Sartori, 2008). Agents may have inconsistent beliefs, and conflict may thus result for instance from the overconfidence of both parties (Slantchev, 2007). Another form of asymmetric information leading to conflict is linked to the motivations of the agents. If a rational agent thinks that there is a (small) probability of being faced with an irrational foe, the rational agent can choose to arm and fight (Waltz, 1959; Schelling, 1963; Kydd, 1997; Baliga and Sjostrom, 2004, 2009). The fear that the adversary will become stronger in the future may also be a reason for conflict (see the discussion in Taylor (1954) for the case of wars between great powers). A State consolidation period during which power may shift in favor of the adversary is a context where preventive conflict may occur (Powell, 2012). Mass killing can be interpreted as a strategy to reduce the future strength of the adversary (Esteban, Morelli, and Rohner, Esteban et al.). Another convincing reason for conflict lies in the possibility of a conflict of interests between the decision maker and the rest of the group represented. Jackson and Morelli (2007) and Bevia and Corchon (2010) argue that conflict may arise when the decision maker expects greater benefits (gains or glory) than his group (the citizens in the case of interstate conflicts) or when the decision maker does not internalize all the costs that his group bears.[6] Querou (2010) shows that elected leaders may decide to go to war because they anticipate that they will free-ride on the fighting efforts of their group members. Small-scale or limited conflicts can emerge because they convey information about the relative strength of the adversaries (Sanchez-Pages, 2009).

A fascinating research topic is the timing of conflict.[7] When do conflicts arise and when do they end? Why and when do conflicts stop and start again? Garfinkel (1990) shows that peace can be supported as an equilibrium when sufficiently patient players use punishment strategies and Leventoglu and Slantchev (2007) and Yared (2010) show that temporary wars may arise in equilibrium in two different models. Yared (2010) consider a model with incomplete information (and he focuses on sequential equilibria) whereas Leventoglu and Slantchev (2007) consider a complete information model where adversaries have limited fighting capacities (and they focus on renegotiation proof equilibria). Bester and Konrad (2004) show that conflict (contest) may be delayed when there is asymmetry between defense and attack.[8] Bester and Konrad (2005) show that contestants have incentives to delay conflict until the stochastic strength (capacity) of the adversary is sufficiently low. A contestant may also delay conflict because the cost of conflict in the current period is larger than the future (discounted) expected benefits of winning the conflict (Polborn, 2006). Jackson and Morelli (2009) explore the dynamic incentives of adversaries to invest in armaments as a deterrence strategy (which may delay conflict). Acemoglu et al. (2012) and Sekeris (2014) develop theories of (exhaustible) resource conflicts. Acemoglu et al. (2012) consider a two country model where the firms in the resource rich country fail to internalize

[5] Conflict also emerges when there is an advantage to attack first (Powell, 1993; Fearon, 2005; Chassang and Padro i Miquel, 2010; Morelli and Rohner, 2010).

[6] Indivisibility of the contested resource eliminates some peace agreements and can also lead to conflict. Jackson and Morelli (2011) also argue that multilateralism may lead to bargaining failure.

[7] For an overview of dynamic contest models, see Konrad (2009) and Konrad (2012) for a focus on the "discouragement effect".

[8] For models of contest with attack and defense, see also the literature on sabotage in contests and tournaments, e.g. Lazear (1989); Bester and Konrad (2000); Chen (2003); Krakel (2003); Gurtler (2008) and Soubeyran (2009).

the negative externality of their extraction on the increased likelihood that the resource poor country decide to attack. Firms then tend to extract the resource faster, which in turn increase the incentives for the resource poor country to launch a war. Sekeris (2014) consider a common pool resource problem and show that conflict arises when the resource becomes scarce.[9] Finally, Powell (2013) proposes a theory of the pace of State consolidation in which consolidation occurs thanks to peaceful negotiations that weaken the rebel group and/or violent conflict that may lead to the end of the rebellion.

2.2 Water Scarcity and Civil Conflict

The seminal paper by Miguel et al. (2004) has opened a debate on the link between water scarcity and civil conflict. The sub-Saharan African region serves as the main source of information on this question. This region has been riddled with civil conflicts; 29 countries in the region have experienced a civil war during the 1980s and the 1990s. Moreover, African countries depend on rain-fed agriculture and agriculture accounts for more than 50% of the GDP in a majority of African countries (World Bank, 2011). Barrios et al. (2010) show that rainfall has been a significant determinant of poor economic growth for Africa and they also show that this is not true for the other regions of the world. They show that the drop in rainfall is responsible for 15%-40% of the gap in African wealth (per capita) relative to developing countries. These peculiarities make the focus on Sub-Saharan Africa relevant to highlight a potential relationship between climate and civil war.

Both capacity and opportunity suggest the existence of a climate-conflict relationship. The opportunity-related effect of climate suggests that drought may increase the likelihood of civil conflict because rebelion groups are generally more "labor" intensive than government forces. A normal climate maximizes the chances to get good and foreseeable harvests and increases the opportunity cost to engage in fighting, which reduces rebel group recruitment. Conversely, drought reduces the agricultural sector production and reduces the wealth of the citizens, decreasing their opportunity cost to engage in fighting, which favors rebel group recruitment. The capacity-related effect also suggests a positive drought-conflict relationship because the fiscal capacity of the government (Besley and Persson, 2010) is generally high compared to the appropriation capacity of the rebel groups.

Burke et al. (2009) focus on the direct link between climate and civil war and use climate projections to predict the likelihood of future civil wars. They study a reduced form relationship between rainfall, temperature, and civil war and show that higher temperatures increase the likelihood of civil war.[10] Their estimates (using historical data) show that a 1 degree Celsius increase leads to a 49% increase in the likelihood of civil war incidence. Projected climate models lead the authors to conclude that there will be a 54% increase in the likelihood of civil war incidence by 2030. Hsiang et al. (2011) associate climate changes on a global scale with global patterns of civil conflict. They identify a relationship between the El Niño Southern Oscillation

[9] On resource conflicts, see also (Soubeyran and Tomini, 2012). They develop a simple model of water shortages and conflict.

[10] See Buhaug (2010), Burke et al. (2010b), Buhaug et al. (2010) and Burke et al. (2010a) for a debate on the robustness of this link.

from 1950 to 2004 and the probability of new civil conflicts. They show that the Southern Oscillation may have played a part in 21% of all civil conflicts. Couttenier and Soubeyran (2014) show that the link between rainfall, temperature and civil war found in the literature may be driven by aggregate shocks (such as global climate) that were not accounted for. A standard specification relying only on within country variation reveals a much weaker and insignificant link between weather variables and civil war. To increase statistical power, they propose an alternative measure of climate with the *Palmer Drought Severity Index* and continue to find a weak positive link between drought and civil war. Harari and Ferrara (2012) focus on Africa over 1997-2011 at a disaggregated level (0.5 $\times$ 0.5 degree). They show that drought during the growing season of the main crop cultivated in a cell increases the likelihood of civil conflict in that cell. Maystadt and Ecker (2014) show that temperature anomalies have increased the likelihood of civil conflict in Somalian's regions (over 1997-2009) and Maystadt et al. (2014) show that temperature anomalies have increased the frequency of violent conflict by 32% in Sudanese regions over the 1997-2009 period. In a meta analysis, Hsiang et al. (2013) consider 60 quantitative studies. They argue that there exist a convergence of the results that support a causal link between climate and conflicts. They claim that the magnitude of the effect of climate is substantial.[11] A 1 standard deviation change in climate (i.e. a higher temperature and extreme rainfall), they expect the intergroup conflict to rise by 14%.

Data issues. Regardless of the quality of the data, rainfall and temperature are not sufficient to characterize drought. Other factors, such as the yearly distribution of rainfall and the accumulation capacity of the soil matter. For a given amount of rainfall (or temperature), it is important to take into account the duration of the time period of accumulation and the capacity of the soil to support or accumulate this quantity of rain. A same quantity of rainfall also has different implications for countries depending on their geographic location, the quality of their soil, and their agricultural specialization. Some authors use richer indices such as the *Palmer Drought Severity Index* (PDSI) which is based on a hydrological model and depends on local conditions and on climatic history (Palmer, 1965). Data is available since 1870 at 2.5 latitude and longitude degree intervals. The PDSI values in two different countries with the same current temperature and rainfall levels may differ because of differences in local conditions (e.g. the duration of the day, or the characteristics of the soil). The PDSI values in a country at two different dates with the same temperature and rainfall levels may also differ because the PDSI takes the local climatic history into account. The PDSI is a much richer measurement of drought than the level of precipitations or temperature. Thus, the analysis is not subject to criticisms regarding the choice of the variable (rainfall or temperature) or regarding the choice of the climate model (level or growth rate). The Standardised Precipitation-Evapotranspiration Index (SPEI)[12] is an alternative to the PDSI. The SPEI has the practical advantage to be simple and available at a more disaggregated level than the PDSI.[13] The PDSI has the advantage to be grounded

[11] See Hsiang and Burke (2014), Buhaug et al. (2014) and Hsiang et al. (2014) for a debate on this claim.

[12] This index was first developed in Vicente-Serrano et al. (2010).

[13] See Ciccone (2011) and Miguel and Satyanath (2011) for a discussion on the appropriate way to model climate. However, note that their discussion focuses on the use of lagged climate variables instead of climate variations, but does not discuss the hydrological relevance of the climate index.

on a theoretical model (Dai, 2011).[14] The Weighted Anomaly Standardized Precipitation Index (WASP)[15], is a measure of precipitation deviation from normal. The WASP index is based on precipitation only, while the PDSI and SPEI is based on precipitation, temperature, soil horizon thickness and texture, vegetation and texture-based estimates of the available soil moisture. Global climate variations (El Niño Southern Oscillation) are also used instead of idiosyncratic variations of rainfall and temperature, and they analyze the link between global climate and a global measure of the risk of civil conflict.[16]

In the present analysis, we use weather data and two common water stress indices that are used in the context of water river basins: the Falkenmark index and the Water Dependency Index (see below for a detailed discussion). They differ from weather measures as they measure water availability on a territory, taking into account water from river basins. They differ from drought indices such as the PDSI, the SPEI or the WASP which are based on weather data and evapotranspiration.

2.3 Water Scarcity and International Conflict and Cooperation

In this section, we move away from the growing literature on water scarcity and civil conflicts and focus the relationship between water scarcity and international conflict and cooperation. While some case studies from the Middle East (Cooley, 1984) and Northern Africa (Starr, 1984) have suggested that water scarcity might lead to international conflict, historical data provides no explicit examples of international water war while cooperation is relatively frequent (Wolf, 1998). The existing empirical literature then mainly focuses on international cooperation. This burgeoning literature focuses on three main decisions: negotiation and signature of international cooperation treaties (Song and Whittington, 2004; Espey and Towfique, 2004; Dinar et al., 2010; Zawahri and Mitchell, 2011), dams building decisions (Olmstead and Sigman, 2015), and transboundary pollution management (Sigman, 2002; Bernauer, 2010).

The literature on international cooperation treaties has studied the correlates of these treaties, more precisely the kind of local conditions that seem to be associated with cooperation. Song and Whittington (2004) provide a descriptive analysis of local characteristics that are associated with the existence of a formal treaty between countries (a treaty was signed after 1950 versus no treaty was signed after 1950). They find that cooperation treaties are more likely to exist in Europe while they are less likely to exist in locations where the basin cuts a border or forms a border. Espey and Towfique (2004) also provide a cross-sectional analysis that links local characteristics and the likelihood of the existence of a formal cooperation treaty signed (a treaty was signed during the 1944-1998 period versus no treaty was signed during this period) between two countries in a river basin. Their results indicate that the existence of a treaty is more likely in river basins where the basin is smaller as a percent of a country's size and where the basin is shared among a larger number of countries. Dinar et al. (2010) focus on precipitation and runoff

[14] Vicente-Serrano et al. (2010) argue that the SPEI has the advantage over the PDSI to be able to depict droughts on time scales shorter than 12 months. However, this criticism is not a problem because the monthly values used to compute the PDSI can be used to depict such droughts (Dai, 2011). Dai (2011) provides a criticism of the SPEI. He argues that it is the actual evapotranspiration and not the potential evapotranspiration that affects the water balance. The problem is that the SPEI uses the latter.

[15] This index was first developed in Lyon and Barnston (2005). Levy et al. (2005) uses this measure in a study on conflict.

[16] However, the perspective of the studies which use a global measure is quite different, see Hsiang et al. (2011).

variability on the likelihood and the intensity of cooperation (i.e. likelihood of the existence of a treaty and the number of treaties). They correlate river basin averages of yearly precipitation and runoff variability with the existence/non existence (or the number) of a treaty for the management of the basin. They find an inverted U-shaped relationship between precipitation and runoff variability and cooperation, i.e. that cooperation is more likely in basins where precipitation and runoff are intermediate. They also find that there is more cooperation between countries which trade more and have more diplomatic relations, while there is less cooperation between countries with uneven wealths. Zawahri and Mitchell (2011) distinguish between bilateral and multilateral treaties. To our knowledge, their study is one of the very few studies that take advantage of the time dimension of the data (which is available for the 1816-2007 period) and considers a basin dyad-year analysis. They find that water dependence is correlated with the likelihood of the signature of a cooperation treaty whenever the basin is shared between two or more countries and whenever they focus on bilateral or multilateral treaties.[17] They also find that power advantages for upstream countries are correlated with bilateral cooperation treaties, while power parity is correlated with multilateral cooperation treaties.

A recent paper focuses on a related topic, the decision to build dams over water rivers (Olmstead and Sigman, 2015). It focuses on the presence and the number of dams that were build over the whole time period in a subbasin-country. They find that there are more dams in areas in upstream countries than in downstream countries and that international cooperation treaties are more likely to be present in locations with a smaller number of dams. A reason why countries upstream build more dams than downstream countries is that upstream countries do not internalize the cost they impose on downstream countries.

While the literature is mainly focused on the quantity of available water (precipitation, runoff, water dependency), few studies (Sigman, 2002; Bernauer, 2010) focus on water quality (pollution) in transboundary settings. They find that water pollution levels are higher near international borders, which suggests that countries free ride on water quality because they do not take pollution that is received by foreign countries into account. However, Sigman (2002) acknowledge that, when using standard difference-in-difference estimates (using country and year fixed effects), the effect becomes negative and non significant.

A limit of this literature is that the results obtained cannot be interpreted as causal effects for at least two reasons. First, most of the studies do not take advantage of the time dimension and instead focus on whether or not a treaty has been signed over the whole period. Thus they provide information on where cooperation occurs and what are the local conditions in these places. One cannot conclude, even if the locations share some common local conditions, that these conditions indeed caused cooperation or the absence of cooperation. Indeed, there may be other common local characteristics that are not included in the analysis (maybe because they are unobserved) that are the true causes of cooperation. Second, one cannot conclude as regards the direction of the causal chain. Indeed, a positive and significant correlation between, for instance, water dependency and the existence of a treaty may exist because water dependency increases the likelihood of cooperation or because cooperation leads to more water dependency.

[17]To capture the distribution of power, they use the CINC capabilities ratio. This is a national index developed by Singer, Bremer, and Stuckey (1972), which captures power in six areas: iron and steel production, energy production, urban population, total population, military expenditures, and military personnel. The data comes from the Correlates of War (COW) Project: http://www.correlatesofwar.org

In Section 4, we explain how we tackle this issue in our analysis.

Data issues. The papers in the literature use the Transboundary Freshwater Dispute Database (TFDD) that comes from the Department of Geosciences, Oregon State University. This dataset contains more than 400 international water basin agreements over the 1816-2007 period. Dinar et al. (2010) uses this dataset as well as ancillary data sources. In the present study, we use the International Rivers Cooperation and Conflict (IRCC) database (Kalbhenn and Bernauer, 2012) that covers a shorter period of time (1997-2007). However, it contains all river basin-country pair-years and it contains more events than the TFDD dataset.

3 Data

The International Rivers Cooperation and Conflict database (Kalbhenn and Bernauer, 2012) provides ideal information to study the relationship between water stress and international cooperation and conflict. Crucial information for a river basin level analysis includes information on countries that share river basins, temporal variations in cooperative and conflict events, temporal variations in water stress indices and weather at the river basin level, and temporal variations in countries national production, agricultural production, population characteristics, quality of institutions and democracy indices. Hence, a substantial amount of work has been dedicated to the data construction using river basin level and country level data. This investment in putting together novel water stress data and available cooperation and conflict as well as economic, demographic and political data enables us to carry out a new analysis.

3.1 Data on International River Basins

Our main data source is the International Rivers Cooperation and Conflict database (IRCC). Kalbhenn and Bernauer (2012) provides an extensive event dataset on international river basin worldwide for the time-period 1997-2007. This dataset covers 264 international river basins. Our final sample contains 256 international basins. Most international river basins are shared between 2 countries, some between 3 or 4 and only very few between 5 or more countries.

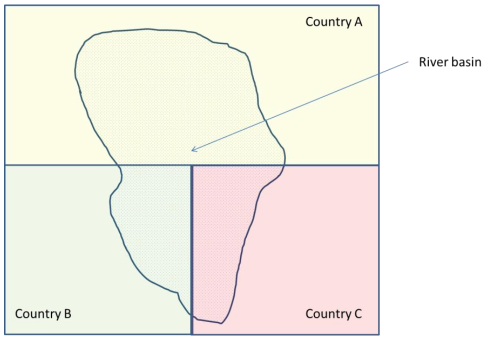
Figure 1 provides an example for an IRB shared among 3 countries. For each IRB, we have information on the occurrence of water cooperation or conflict for each pair of countries sharing the IRB, that is $\{\text{country A}, \text{country B}\}$, $\{\text{country A}, \text{country C}\}$ and $\{\text{country B}, \text{country C}\}$.

The aim of this paper is to study to what extend climate influences cooperation and conflict at the international water basin level. Throughout the paper, we develop a dyadic approach. Our unit of analysis is then country i × country j × basin b. Table 1 provides summary statistics for the geography of basins, that is for the joint distribution of country pairs and basins. There are 1013 country pairs and 256 basins in our sample. The number of pairs of countries per basin varies from 1 to 154. Most of the basins are shared by only two countries and 3/4 of basins are shared by less than three countries (three pairs of countries). The number of basin by pair of countries varies from 1 to 17, the average being around 2. However, most of country pairs shares no more than one basin.

3.2 Data on Cooperation and Conflict

As for international river basins, our main source of data as regards cooperation and conflict

Figure 1: Example of a river basin shared by 3 countries



Source:

Table 1: Geography of Basins and Countries: Summary Statistics

	Min	1^{st} quartile	Median	3^{rd} quartile	Max	Mean	Obs.
Nb country pair/ basin	1	1	1	3	154	3.96	256
Nb basin/ country pair	1	1	1	2	17	1.79	1013

Notes: International Rivers Cooperation and Conflict (IRCC) database (Kalbhenn and Bernauer 2012).

events is the International Rivers Cooperation and Conflict (IRCC) database (Kalbhenn and Bernauer 2012). The database contains more than 15,000 dyad-year observations. Information on water related events was retrieved from news media reporting made accessible through BBC Monitoring (http://www.monitor.bbc.co.uk/). Water related events between riparian countries are characterized on the International Rivers Cooperation and Conflict ($IRCC$) scale ranging from -6 (most conflictive) to +6 (most cooperative). Table 2 provides summary statistics of our cooperation and conflict indices. See table 14 in appendix for more information on the scale. Our final sample contains up to 10,272 dyad-year observations in the case of cooperation and 9,167 dyad-year observations in the case of conflict.[18] We use measures of the incidence of cooperation and conflict which is standard in the conflict literature (Blattman and Miguel, 2010). We build two dummy variables that are coded 1 if at least one event occurs during the year between the countries of the dyad. *Cooperation* is coded 1 for each dyad-year with at least one cooperation event ($IRCC > 0$) and *Conflcit* is coded 1 for each dyad-year with at least one conflict event ($IRCC < 0$). A cooperation event is recorded for 11 % of the dyad-year observations while a conflict event is recorded for only 1% of the dyad-year observations. We also use the number of events as a measure of the intensity of cooperation and conflict: *Nb of Cooperation* is the number of cooperation events ($IRCC > 0$) within the year for the countries of the dyad and *Nb of Conflict* is the number of conflict events ($IRCC < 0$) within the year for the countries of the dyad. The number of cooperation events in a year between two countries varies from 0 to 16 and there is on average 1 cooperation events each 4 years between two countries. The number

[18]The sample size is slightly different from the original dataset because of missing data in our final sample.

Table 2: Cooperation and Conflict: Summary Statistics

	Min	Max	SD	Mean	Obs.
Nb of Cooperation	0	16	1.06	0.27	10272
Cooperation (yes/no)	0	1	.32	.11	10272
Nb of Conflict	0	11	.17	.01	9167
Conflict (yes/no)	0	1	.07	.01	9167

Notes: Authors computation from the final sample.

of conflict events in a year between two countries varies from 0 to 11 and there is on average 1 conflict events each 100 years between two countries.

Figure 2 displays the number of cooperation and conflict events from 1997 to 2007. The number of conflict events is quiet stable over the period, except from 2001 to 2003 with on average 100 conflict events by year. The number of cooperation events is on average three time higher than the number of conflict events. Years 2000-2001 and 2004-2006 were the years with the hight level of cooperation events (around 500 events by year). Figure 3 provides a similar conclusion with a different approach. We report the estimated coefficients of a correlation between the number of conflict or cooperation events and yearly dummies.[19]

The year of reference is 1997. We observe that the level of cooperation is significantly higher in the years after 1997 (around 20% in 2004 and 2006). The number of conflict in comparison to 1997 is also higher in most of the years after 1997 but the magnitude is less important.

In the empirical strategy we explain why we have to consider carefully this yearly differences in the number of conflict or cooperation events.

3.3 Water Stress Data

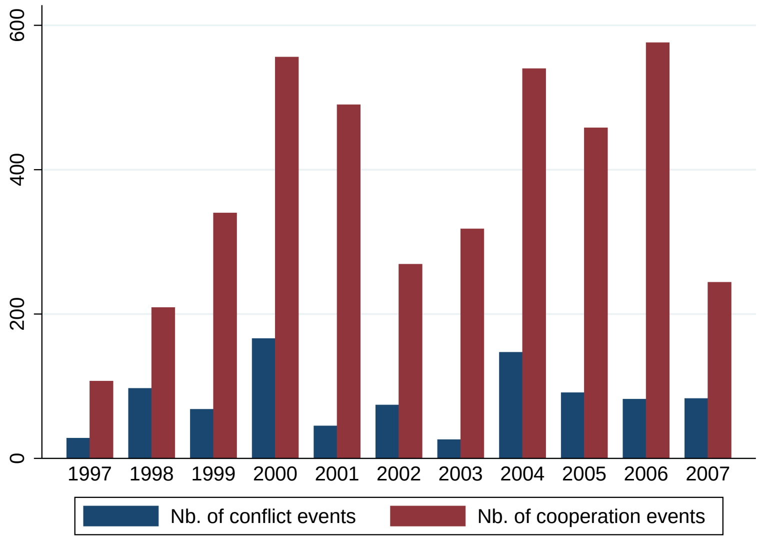
We use new water stress and weather data computed by the Joint Research Center of the European Commission. Table 3 provides summary statistics of the water stress and weather indices used in the present study. The weather data reveals that overall precipitation (in mm per year) and temperature over international river basins are not very dispersed, the standard deviation of precipitation being 1/10 of the 7 millimeters per year average and the standard deviation of temperature being only 3 percent of the 290 Kelvin average (around 17°C). Temperature amplitude, defined as the difference between the maximal daily average temperature and the minimum daily average temperature, is much more dispersed, the standard error being more than forty percent of the average. Our data also contains more elaborated water stress indices. *Areas w/o water dependency* and *Areas w/ water dependency* are two dummy variables based on the Water Dependency Index (WDI). The WDI is equal to the difference between the national water demand and the national water available divided by the inflow from upstream regions. There are two critical values, 0 and 1. When the WDI is less than 0, water demand is smaller than available water, then local water needs are covered by local water resources. When the WDI is

[19] We estimate the following equation:

$$Event_{ijbt} = \mathbf{FE_t}\beta + \varepsilon_{ijbt}, \tag{1}$$

where $\mathbf{FE_t}$ is vector of year dummies. 1997 is the reference year. Figure 3 displays the yearly estimates of β.

Figure 2: Dummies

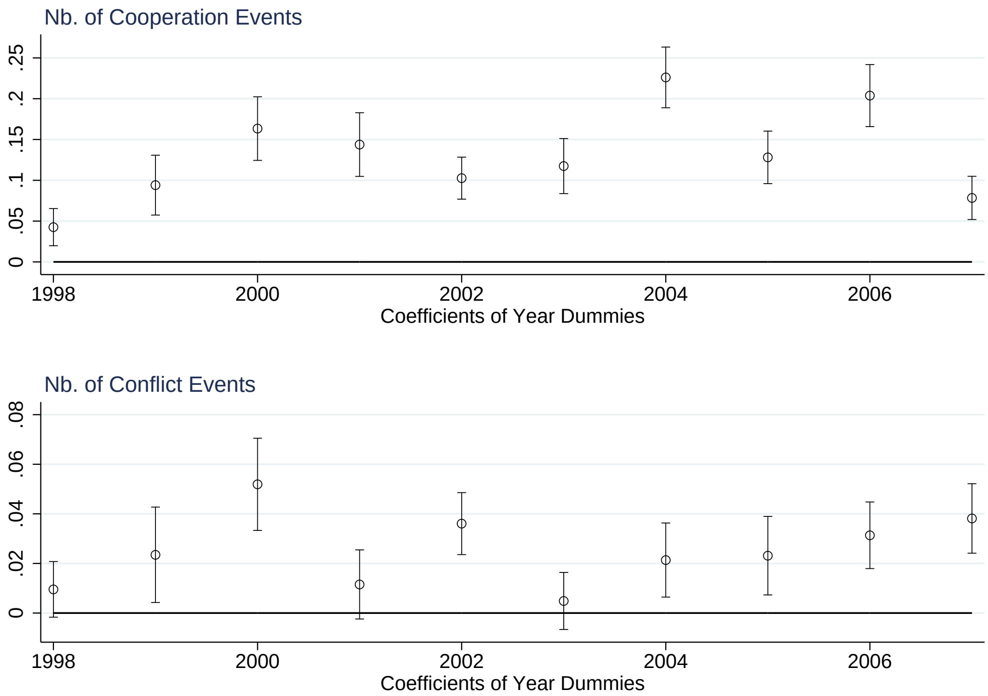


Source: Authors computation from the final sample.

greater than 1, water demand is larger than available water and the difference is larger than the inflow from upstream regions. Local water needs are then not covered by local water resources and the inflow from upstream countries does not cover the remaining demand. *Areas w/o water dependency* is a dummy variable which is 1 when $WDI < 0$. *Areas w/ water dependency* is a dummy variable which is 1 when $0 < WDI < 1$. The reference is $WDI > 1$. 90 % of the observations in the sample correspond to areas without water dependency ($WDI < 0$), less than 1 % to areas with water dependency and covered needs ($0 < WDI < 1$) and 9% to areas with water dependency and needs are not covered ($WDI > 1$). Our data also contains two measures of the Falkenmark water stress index. The Falkenmark index is a measure of water availability per capita (measured in m^3 per capita per year). *Falkenmark index (local water only)* takes only water locally available that does not take into account the inflow from upstream regions whereas *Falkenmark index (including water from upstream)* takes into account the inflow from upstream regions. The summary statistics of these two measures are similar, with a 10 m^3 per capita per year average, a minimum of about 4 m^3 per capita per year and a maximum around 20 m^3 per capita per year.

Issues with water stress data. Before going further, we have to mention that, if one wish to estimate the causal effect of water stress on conflict and cooperation, none of these index is fully satisfactory. The WDI and the Falkenmark index have the advantage to be commonly used in hydrology and to capture water stress quite well. However, as they depend on water use, they may be suspected to be endogenous to conflict and cooperation. In other words, conflict and cooperation events affect water use and then the WDI and the Falkenmark index. Our estimates that use these index have then to be interpreted as correlations and not as causal effects. Weather variables have the advantage to be less affected by water use. However, weather variables are not measures of water availability and they describe social exposure to water stress in a less efficient way than the WDI and the Falkenmark index (see the previous discussion on

Figure 3: Dummies



Source: Authors computation from the final sample.

Table 3: Water Stress: Summary Statistics

	Min	Max	SD	Mean	Obs.
Yearly Precipitation - mm/yr	2.53	8.63	.65	6.77	10329
Yearly Average Daily temperature (°C)	-12.48	29.79	8.82	17.05	10329
Temperature Amplitude (°C)	1.20	18.85	2.64	10.89	8313
Areas w/o water dependency	0	1	.31	.89	10329
Areas w/ water dependency & covering their needs.	0	1	.09	.01	10329
Falkenmark index (local water only)	3.59	20.17	1.81	9.37	10329
Falkenmark index (including water from upstream)	4.13	20.27	2.05	11.41	10329

Notes: Our sample contains 10329 observations for which we have information about yearly indices of conflict or cooperation events between pairs of countries.

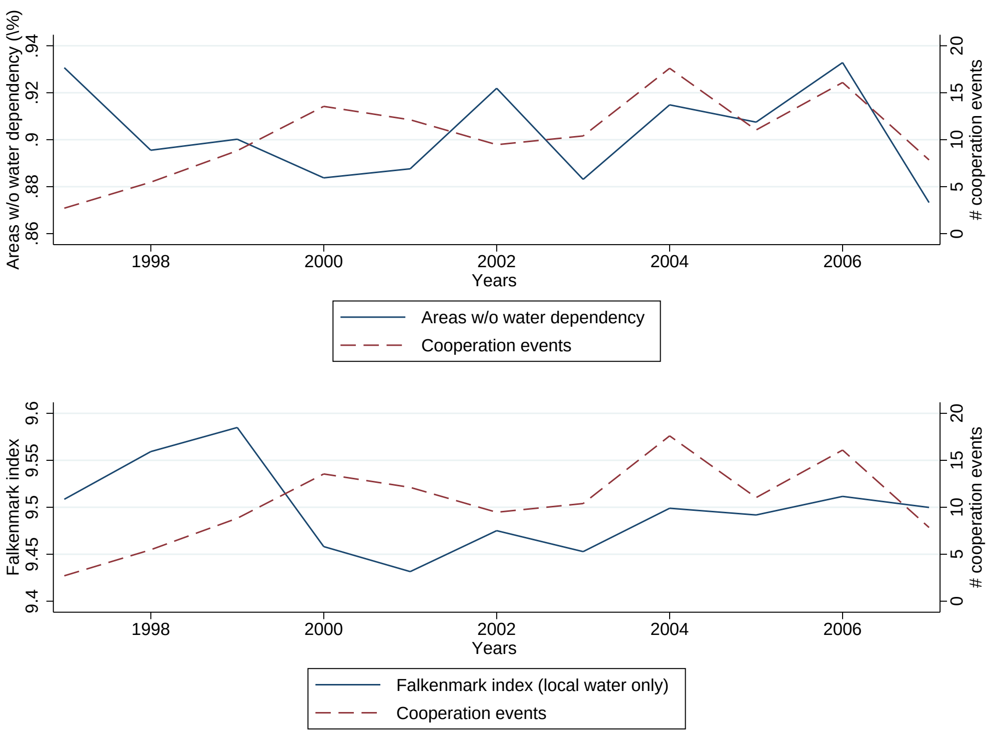
the climate indicators).

4 Empirical Strategy

4.1 Preliminaries: Water Stress, cooperation and conflict time series

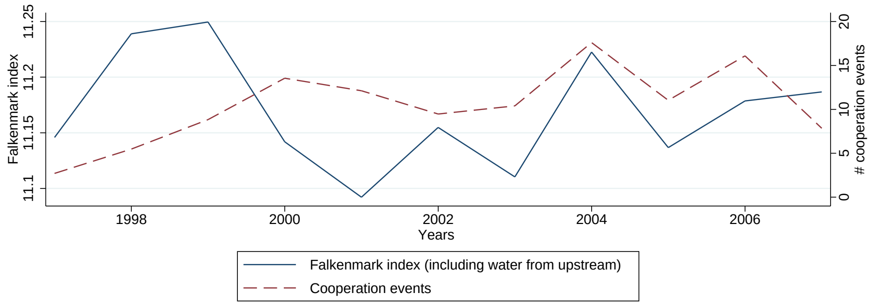
Time series plots of the intensity of cooperation (number of cooperation events), the intensity of conflict (number of conflict events) and the various water stress indices are provided in Figures 4 to 6. These time series highlight that the evolution of the number of cooperation seems to be negatively correlated with precipitation (the correlation is -0.41), positively correlated with the yearly average daily temperature (the correlation is 0.48) and negatively correlated with the Falkenmark index which include local water only (the correlation is −0.33). The number of conflict seems to be positively correlated with the yearly average daily temperature (the correlation is 0.45). However, none of these correlation coefficients is significant at standard levels. The apparent lack of relationship between cooperation/conflict and water stress may be due to worldwide events that affect cooperation and conflict that are not due to water stress variations. This may be also due to the heterogeneity of local conditions (such as historically specific diplomatic relationships). As explained in the next section, we include country-pair basin and year fixed effects in order to escape these concerns. The omission of these fixed effects may generate a spurious regression phenomenon (Granger and Newbold, 1974). In other words, one may conclude that there is a no link between water stress indices and cooperation/conflict only because the relationship is hidden by aggregate time series variation or by country-pair basin heterogeneity.

Figure 4: Evolution of water stress indices and cooperation events - I



Source:

Figure 5: Evolution of water stress indices and cooperation events - II



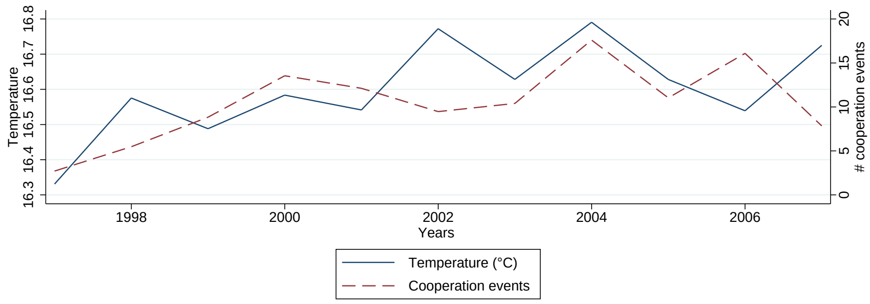
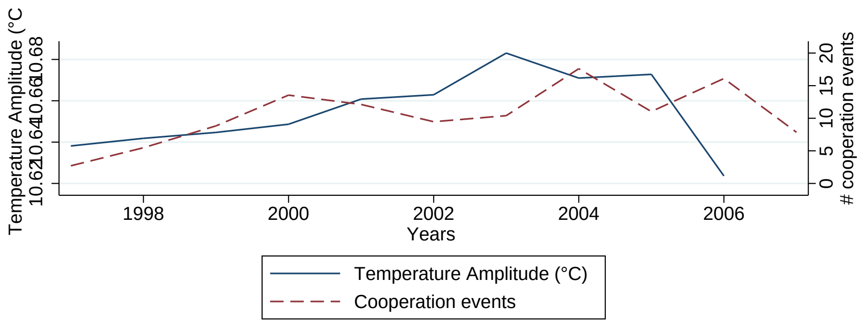
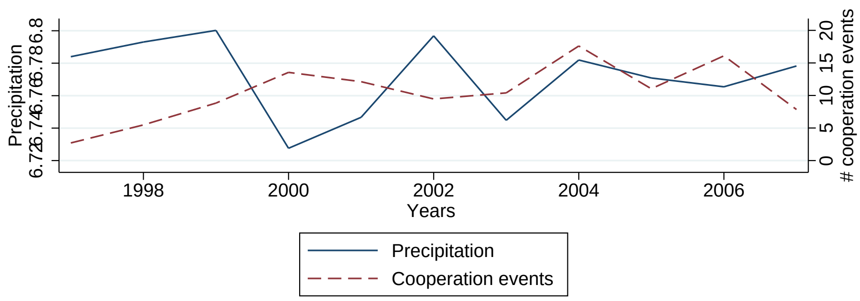


Figure 6: Evolution of water stress indices and cooperation events - III





4.2 Difference-in-difference strategy

Our empirical strategy follow three distinct steps. Our unit of analysis is country i × country j × basin b.

In a first step, we estimate the effect the following equation:

$$Event_{ijbt} = \alpha WaterStress_{bt} + FE_{ijb} + FE_t + \varepsilon_{ijbt}, \quad (2)$$

where $Event_{ijbt}$ is either an index of cooperation or an index of conflict between countries i and j over basin b in year t. $WaterStress_{bt}$ is either an index of water stress or a measure of weather for basin b in year t. The fixed effects FE_{ijb} and FE_t are respectively the country pair - basin and year fixed effect. The fixed effects filter out all bilateral time-invariant basin characteristics and year-specific events that affect cooperation or conflict. Given that most basins are shared by only two countries and that most country-pairs share only one basin (see Table 1), it is quite fair to interpret α as the average effect of a water stress variations on variations of the occurrence of the event within a country pair-basin.

In a second step, we control for potential co-determinants of cooperation and conflict, we also include economic, demographic and political time-varying dyadic variables:

$$Event_{ijbt} = \alpha WaterStress_{bt} + \mathbf{X}_{ijt}\beta' + FE_{ijb} + FE_t + \varepsilon_{ijbt}, \quad (3)$$

where $\mathbf{X}_{ijt}$ is a vector of time-varying dyadic variables which include economic variables (GDP per capita, whether the countries are net exporters of Oil or Gas, the share of agricultural production to GDP), demographic variables (the percentage of rural population), and political variables (the quality of institutions and the level of democracy/autocracy).

In equations 2 and 3, the estimated coefficient ($\hat{\alpha}$) captures the average effect of water stress on the conflict and cooperation events. Implicitly, we assume that the effect of water stress is homogenous across countries×basin and time. Last, we allow the average effect to be different across countries×basin according to country characteristics. We estimate an extended version of the equation 3:

$$Event_{ijbt} = \alpha WaterStress_{bt} + \mathbf{X}_{ijt}\beta' + WaterStress_{bt} \times \mathbf{X}_{ijt}\gamma' + FE_{ijb} + FE_t + \varepsilon_{ijbt}, \quad (4)$$

where $WaterStress_{bt} \times \mathbf{X}_{ijt}$ is the interaction between water stress and the time-varying dyadic variables. The effect of water stress on the occurrence of the event is then $\alpha + \mathbf{X}_{ijt}\gamma'$ and depends (linearly) on the time-varying dyadic variables.

5 Results

As mentioned earlier, we use basin specific water stress indices and focus on the effect of the impact of changes in water stress on the occurrence of cooperation and conflict events between countries which share international water river basins. The expected sign of the effect is unclear. On the one hand, as mentioned in the literature section, existing evidence shows that water stress, i.e. an increases in temperature, a decrease in precipitation or a worsening in drought increases the likelihood of conflict (Burke et al., 2009; Hsiang et al., 2013; Miguel et al., 2004; Couttenier and Soubeyran, 2014). For this reason, one might expect that water stress will increase conflict and decrease cooperation. However, the context of the present study, which focuses on interstate cooperation and conflict, is very different from the context of this literature, which is on civil conflict. On the other hand, the literature on interstate conflicts (Martin et al., 2008) suggests that bilateral dependance decreases the likelihood of conflict. Given that the focus of the present study is on countries that depend from each other because they share water river basins, one may argue that an increase in water stress increases dependance between countries, and then conflict should decrease and cooperation should increase.

5.1 Baseline results: Water stress, cooperation and conflict

Cooperation. Table 4 displays our main results. It provides estimates of the effect of water stress on the number of cooperation events within country pair$\times$basins. Note that for a ease of interpretation, the dependent variable is multiplied by 100. We exploit the overtime variations within country pair$\times$basins to identify a correlation between cooperation events and water stress. We do not find a significant relationship between water stress, as measured by water dependency and covered needs, and cooperation intensity (column 1). However, the Falkenmark indices appear to be positively correlated to cooperation intensity (columns 2 and 3). These results suggest that a one standard deviation increase in the Falkenmark index which includes local water only increases the number of cooperation events by 5% and 7% for the Falkenmark index that includes water from upstream. Temperature and temperature amplitude are also significantly linked to cooperation intensity (columns 4 and 5), while precipitation is not (column 6). A 2°C increase in temperature increases the number of cooperation events by 10%. A 1°C increase in temperature amplitude increases the number of cooperation events by more than 12%. Note that we obtain similar results (in terms of significance) when we use cooperation incidence instead of cooperation intensity as event variable (see Table 11 in the Appendix). All in all, we find piece of evidence of a sizeable effect of water stress on cooperation events.

Conflict. Table 5 displays our results when the event variable is the intensity of conflict (number of conflict). All the water stress indices fails to be significantly associated with the intensity of conflict. We find similar results when we use conflict incidence instead of conflict intensity as event variable (see Table 13 in the Appendix).

Overall, these results suggest that more water stress is associated with more cooperation and water stress is not associated to conflict. This is consistent with the view that dependency (because of shared water river basins) provides incentives for cooperation.

Table 4: Cooperation Intensity: Baseline results

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. var.			Nb. of Cooperation Events			
Areas w/o water dependency	0.22					
	(1.60)					
Areas w/ water depending & covering their needs.	0.64					
	(2.00)					
Falkenmark index (local water only)		3.18***				
		(1.04)				
Falkenmark index (including water from upstream)			3.70***			
			(0.91)			
Yearly Average Daily temperature (°C)				4.93***		
				(0.84)		
Temperature Amplitude (°C)					12.86***	
					(3.97)	
Yearly Precipitation - mm/yr						1.95
						(1.38)
Observations	10,272	10,272	10,272	10,272	8,252	10,272
Adjusted R-squared	0.48	0.48	0.48	0.48	0.46	0.48
Sample mean	12.53	12.53	12.53	12.53	13.61	12.53

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Least squares estimates. Standard errors clustered by dyad in parentheses. All specifications include bilateral × basin and year fixed effects. *Nb. of Cooperation Events* is the (log of 1 plus the) number of cooperation events multiplied by 100.

Table 5: Conflict Intensity: Baseline results

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. var.			Nb. of Conflict Events			
Areas w/o water dependency	-0.30					
	(.45)					
Areas w/ water depending & covering their needs.	-0.29					
	(.27)					
Falkenmark index (local water only)		.05				
		(.22)				
Falkenmark index (including water from upstream)			0.08			
			(0.23)			
Yearly Average Daily temperature (°C)				0.12		
				(0.17)		
Temperature Amplitude					.11	
					(.69)	
Yearly Precipitation - mm/yr						.21
						(.44)
Observations	9,159	9,159	9,159	9,159	7,307	9,159
Adjusted R-squared	0.25	0.25	0.25	0.25	0.16	0.25

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Least squares estimates. Standard errors clustered by dyad in parentheses. All specifications include bilateral × basin and year fixed effects. *Nb. of Conflict Events* is the (log of 1 plus the) number of conflict events multiplied by 100.

Effect of economic, demographic and political variables. Table 6 provides our estimates of the effect of water stress on the intensity of cooperation when we add various economic, demographic and political time varying variables using the specification of equation 3 (see appendix for more details on the variables). First notice that the level of significance and the size of the effect of the water stress variables is very similar compared to those obtained when we do not include economic, demographic and political variables (see Table 4), except the effect of precipitation which is much larger and becomes significant. The quality of institutions and the level of democracy as well as the percentage of rural population or the fact that countries are net exporters of Oil or Gas are not significantly linked to cooperation intensity. GDP per capita and the percentage of agricultural production to GDP are both negatively associated with cooperation intensity. This suggests that increases in wealth and expansions of the agricultural sector may decrease incentives to cooperate.

Definition of cooperation events. The International Rivers Cooperation and Conflict scale ranges from -6 (most conflictive) to $+6$ (most cooperative) (see Table 14). As robustness, we provide estimates for which we only take the most intense cooperation events into account, e.g cooperation events that correspond to an agreement or to a larger cooperation scale (IRCC $>$ 2). The estimates displayed in Table 12 show that the results are robust to this change in the dependant variable.[20]

[20]Unfortunately, we are not able to provide similar estimates for conflict events because of the small number of high scale conflict events in our final sample.

Table 6: Cooperation Intensity: Results with economic, demographic and political variables

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. var.			Nb. of Cooperation Events			
Areas w/o water dependency	0.26					
	(2.27)					
Areas w/ water depending & covering their needs.	-0.59					
	(2.17)					
Falkenmark index (local water only)		4.44***				
		(1.45)				
Falkenmark index (including water from upstream)			4.55***			
			(1.08)			
Yearly Average Daily temperature (°C)				3.20***		
				(.86)		
Temperature Amplitude (°C)					8.23**	
					(3.48)	
Yearly Precipitation - mm/yr						3.57**
						(1.55)
GDP/per cap	-9.69**	-9.47**	-9.58**	-10.09**	-11.00*	-9.65**
	(4.40)	(4.40)	(4.41)	(4.41)	(5.95)	(4.40)
Institutional quality	16.07	15.67	15.67	16.24	18.79	16.00
	(12.67)	(12.69)	(12.63)	(12.61)	(15.19)	(12.66)
Polity score	.47	.44	.45	.52	.62	.46
	(.40)	(.40)	(.39)	(.39)	(.45)	(.39)
Oil/Gas, net exporter	.64	1.32	1.32	.70	1.91	.86
	(6.11)	(6.19)	(6.18)	(6.06)	(7.26)	(6.15)
Agriculture (% GDP)	-0.97***	-0.95***	-0.94***	-0.97***	-1.39***	-0.97***
	(.29)	(.29)	(.29)	(.29)	(.38)	(.29)
Rural population (%)	.54	.58	.57	.49	1.06	.53
	(.54)	(.55)	(.55)	(.55)	(.78)	(.54)
Observations	6,451	6,451	6,451	6,451	5,217	6,451
Adjusted R-squared	0.49	0.49	0.49	0.49	0.48	0.49

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Least squares estimates. Standard errors clustered by dyad in parentheses. All specifications include bilateral × basin and year fixed effects. *Nb. of Cooperation Events* is the (log of 1 plus the) number of cooperation events multiplied by 100.

5.2 Heterogenous effect of water stress on cooperation

Our most prominent results are the effect of weather (precipitation, temperature and temperature amplitude) on the intensity of cooperation. Up to this point, we have focused on average effects of weather. In this section, we go further and look at heterogenous effects. The first question we ask is whether the effect of the weather on cooperation varies when the economic, demographic and political conditions change. The second question we ask is whether the effect of the weather is spatially heterogenous, i.e. varies across regions of the World.

Effect of weather conditional on economic, demographic and political conditions. Tables 8 to 9 provide estimates of the effect of weather variables conditional on economic, demographic or political conditions on the intensity of cooperation. We use the specification of equation 3 (see appendix for more details on the variables). Figures to display the predicted marginal effect of the weather variables on the intensity of cooperation as a function of the economic, demographic or political variables (as well as the 5% confidence interval).[21] Table 7 provides estimates of the effect of precipitation and conditional effects and Figure 7 helps to draw some conclusions. An increase in precipitation decreases cooperation in the poorest countries while it increases cooperation in the wealthiest countries (Figure 7, Column 1). It increases cooperation for countries whose quality of institutions is sufficiently high (Figure 7, Column 3). It decreases cooperation if the share of rural population is sufficiently large (above 60%) but increases cooperation if the share of rural population is sufficiently small (below 30%). These results suggest that an increase in precipitation increases cooperation in developed countries while it decreases cooperation in developing countries.

Table 8 provides estimates of the effect of temperature and conditional effects and Figure 8 helps to draw some conclusions. An increase in temperature increases cooperation for all levels of GDP/cap and the effect is larger for wealthier countries (Figure 8, Column 1). It increases cooperation for all levels of quality of institutions and the effect is larger for countries with a low quality of institutions (Figure , Column 3). It also increases cooperation for (almost) all levels of the share of agricultural in GDP and all levels of the share of rural population. The effect is larger the lower the agricultural share of GDP and the lower the share of rural population. These results suggest that the positive effect of temperature holds for a wide range of economic, demographic and political conditions.[22]

[21] The marginal effect of *WaterStress* as a function of *Variable* is given by $\widehat{\alpha} + \widehat{\beta}\,Variable$. The range of *Variable* is the range of the variable in our data (see Table 15 in the Appendix).

[22] For a sake of space, we do not present the heterogenous effect with the other measures of water stress, but the conclusions are similar.

Table 7: Heterogenous effects: Precipitation

	(1)	(2)	(3)	(4)	(5)
Dep. var.		Nb. of Cooperation Events			
Variable	GDP per cap.	Institutional Quality	Polity IV	% Agricultural	% rural population
Precipitation	0.90	4.52***	3.11**	1.91	0.72
	(1.46)	(1.49)	(1.44)	(1.43)	(1.51)
Precipitation × *Variable*	4.24***	4.60	0.11	-0.33***	-0.32***
	(1.15)	(6.14)	(0.21)	(0.13)	(0.07)
Variable	-5.65	9.16	1.53***	-1.02***	-0.70
	(3.43)	(12.20)	(0.34)	(0.20)	(0.43)
Observations	9,566	7,337	9,426	9,346	10,048
Adjusted R-squared	0.47	0.48	0.48	0.48	0.47

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Least squares estimates. Standard errors clustered by dyad in parentheses. All specifications include bilateral × basin and year fixed effects. *Nb. of Cooperation Events* is the (log of 1 plus the) number of cooperation events multiplied by 100.

Table 8: Heterogenous effects: Temperature

	(1)	(2)	(3)	(4)	(5)
Dep. var.		Nb. of Cooperation Events			
Variable	GDP per cap.	Institutional Quality	Polity IV	% Agricultural	% rural population
Temperature	3.83***	3.54***	4.64***	4.48***	4.15***
	(0.78)	(0.86)	(0.85)	(0.86)	(0.81)
Temperature × *Variable*	0.94***	-4.15***	0.08**	-0.08***	-0.03
	(0.18)	(0.95)	(0.04)	(0.02)	(0.02)
Variable	-7.46**	11.03	1.23***	-0.62***	-0.77*
	(3.43)	(12.80)	(0.29)	(0.18)	(0.45)
Observations	9,566	7,337	9,426	9,346	10,048
Adjusted R-squared	0.48	0.48	0.48	0.48	0.47

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Least squares estimates. Standard errors clustered by dyad in parentheses. All specifications include bilateral × basin and year fixed effects. *Nb. of Cooperation Events* is the (log of 1 plus the) number of cooperation events multiplied by 100.

Table 9: Heterogenous effects: Temperature Amplitude

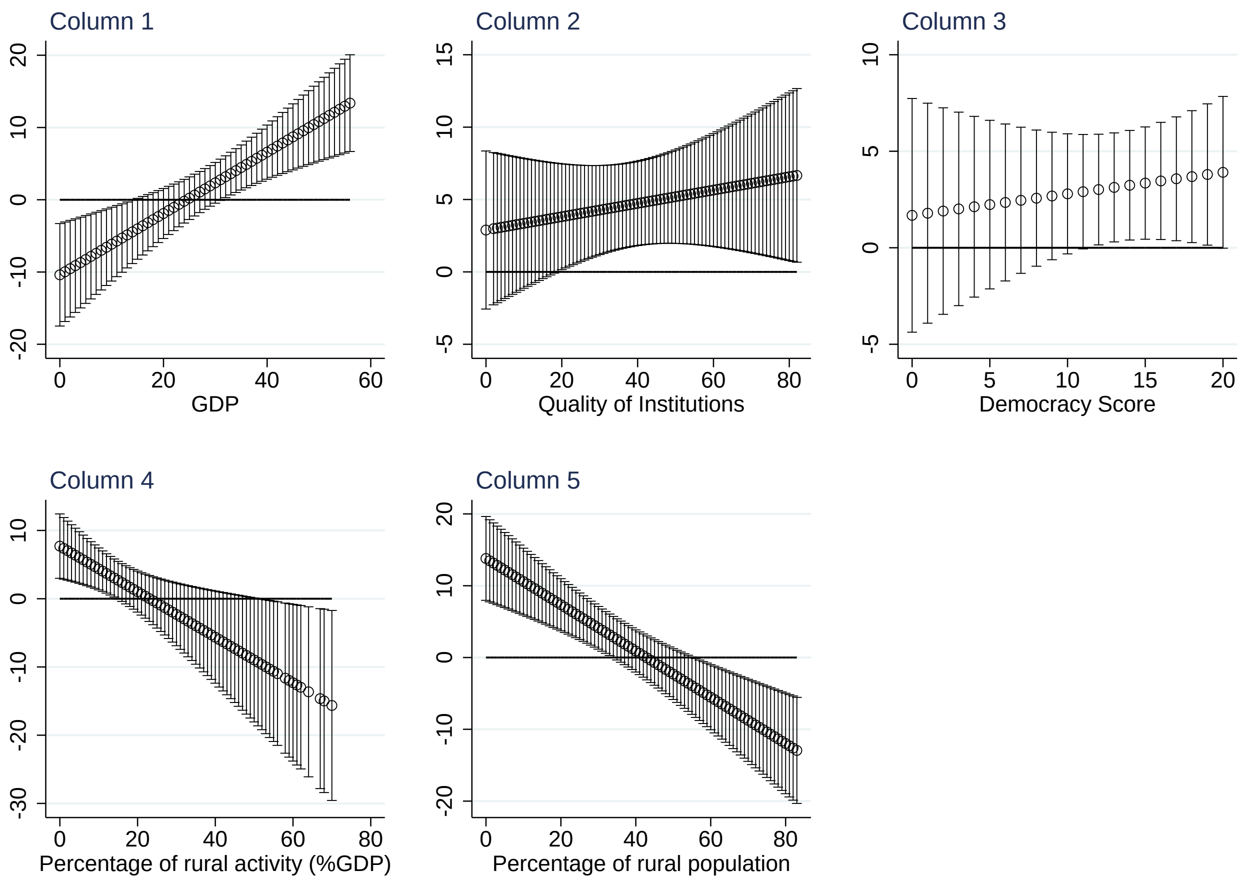
	(1)	(2)	(3)	(4)	(5)
Dep. var.			Nb. of Cooperation Events		
Variable	GDP per cap.	Institutional Quality	Polity IV	% Agricultural	% rural population
Temperature Amplitude	-11.99	12.23***	13.02***	17.01***	23.36***
	(7.33)	(3.84)	(4.40)	(4.14)	(4.91)
Temperature Amplitude × *Variable*	3.08***	-10.72***	0.32**	-0.15*	-0.23***
	(0.78)	(2.47)	(0.13)	(0.09)	(0.07)
Variable	-42.59***	123.54***	-1.96	0.38	1.77*
	(10.01)	(26.86)	(1.49)	(1.07)	(0.93)
Observations	7,606	5,909	7,516	7,487	8,022
Adjusted R-squared	0.45	0.46	0.45	0.46	0.45

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Least squares estimates. Standard errors clustered by dyad in parentheses. All specifications include bilateral × basin and year fixed effects. *Nb. of Cooperation Events* is the (log of 1 plus the) number of cooperation events multiplied by 100.

Effect of Weather by Region. Table 10 provides estimates of the effect of weather variables on the intensity of cooperation for five regions of the world: Africa, East Europe, Latin America, West Europe and North America, and Asia and Pacific. Columns 1 to 3 provide estimates of the effect of temperature, temperature amplitude and precipitation, respectively. We find a large positive effect of temperature on cooperation in Africa, where a 2°C increase in temperature increases cooperation by 30%. We also find that temperature increases cooperation by 8% in Latin America. A 1°C increase in temperature amplitude increases cooperation by 30% in Africa. A one standard deviation increase in precipitation increases cooperation by 50% in Europe and by 35% in Latin America. Asia and Pacific appears to be different from the other regions: temperature decreases copperation to a small extend and precipitation decrease cooperation to a large extend (a one standard deviation increase in precipitation decreases cooperation by 65%). However, as in Africa, temperature amplitude increases cooperation in Asia and Pacific, while the effect is much smaller and our estimate is less precise.

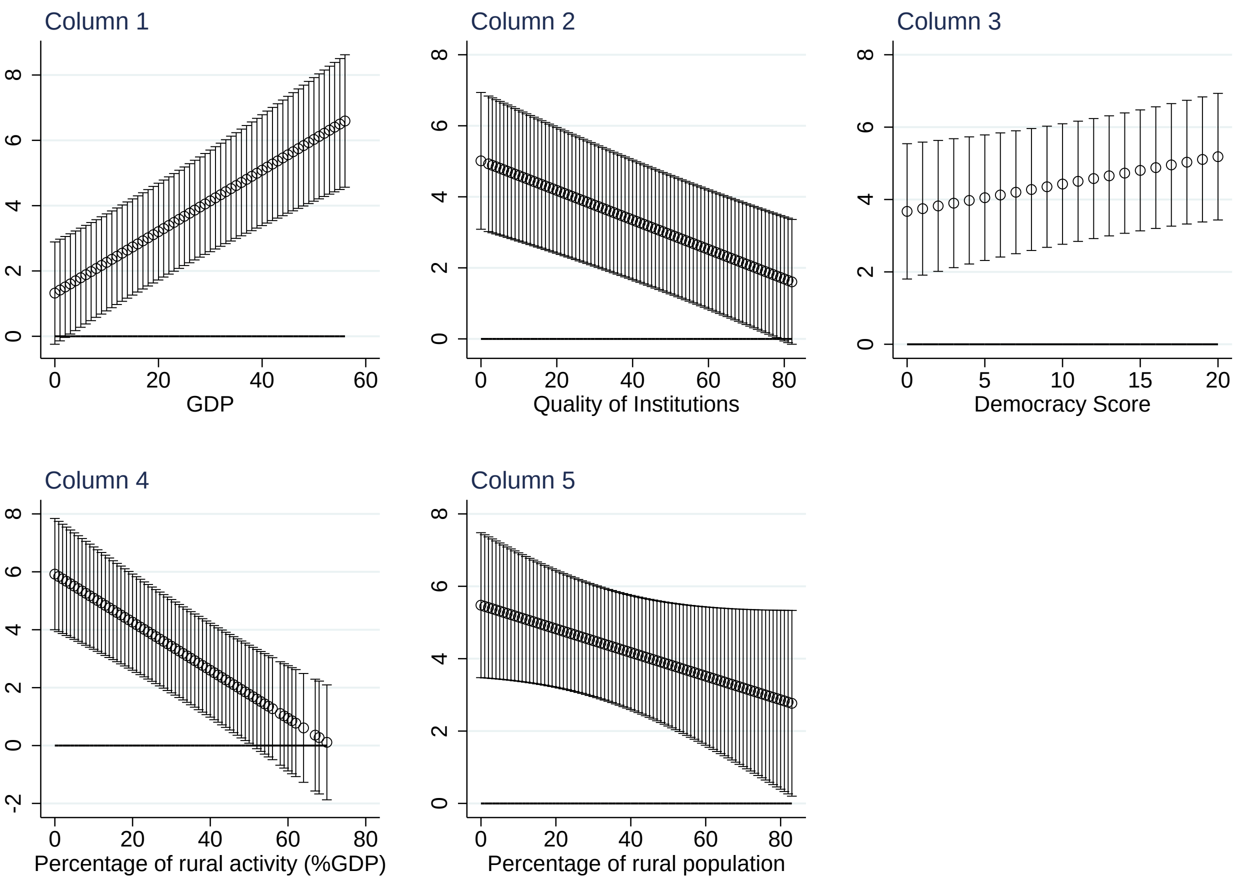
Overall, these results suggest a large positive effect of temperature and temperature amplitude on cooperation in Africa, a large positive effect of precipitation on cooperation in West Europe and America and heterogenous but small effects of temperature variables in the rest of the world. The effect of precipitation is heterogenous but relatively small.

Figure 7: Heterogenous effect: Precipitation



Source:

Figure 8: Heterogenous effect: Temperature



Source:

Table 10: Results by Region

	(1)	(2)	(3)
Dep. var.	Nb. of Cooperation Events		
Climate	Temperature	Temperature Amplitude	Precipitation
Africa × *Climate*	14.53***	28.44***	2.84
	(2.63)	(7.21)	(2.92)
East Europe × *Climate*	1.27	24.51	7.38**
	(1.16)	(15.09)	(3.54)
Latin Ameria × *Climate*	3.94**	-6.52	5.00**
	(1.89)	(4.76)	(2.25)
West Europe × *Climate*	1.39	-4.74	6.59**
	(1.56)	(8.79)	(2.78)
Asia and Pacific × *Climate*	-2.52*	13.36*	-9.46**
	(1.28)	(7.01)	(3.93)
Observations	10,325	8,269	10,325
Adjusted R-squared	0.48	0.46	0.48

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Least squares estimates. Standard errors clustered by dyad in parentheses. All specifications include bilateral × basin and year fixed effects. *Nb. of Cooperation Events* is the (log of 1 plus the) number of cooperation events multiplied by 100.

6 Discussion and Conclusion

In this paper, we analyze the effect of water stress on conflict and cooperation over international river basins. Our analysis covers the exhaustive sample of international river basins over the 1997-2007 period. We have used weather measures as well as novel data on prominent indices of water stress, the Falkenmark index and an index based on the Water Dependency Index. Our main results suggest that, since countries share river basins, they are dependent from each others, and then they tend to cooperate more when water stress increases. We have failed to find a significant effect of water stress on conflict. However, we have argued that these average effects hide some heterogeneity. The effect of temperature is the largest in Africa. The effect of precipitation is very heterogenous and depends on local conditions.

Our analysis has focused on bilateral relationships over international river basins with information on bilateral conflict and cooperation. More detailed data on conflict and cooperation would be needed for a better understanding of these relationships. For instance, more information on the identity of the investigator of conflict or cooperation events would enable to disentangle the decisions of upstream and downstream countries.

As already mentioned, the results that use the prominent water scarcity index (Falkenmark or Water Dependency Index) have to be interpreted as correlations and not as describing a causal relationship because they depend on local water use. Weather data suffer less from this limit but describe social exposure to water stress in a less efficient way than water stress indices. As a conclusion, to assess causal effects of water stress, there is a need of data for water stress indices that do not depend on local human activity.

7 Appendix: Additional Tables

Table 11: Cooperation Incidence: Baseline results

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. var.	Cooperation (yes/no)					
Areas w/o water dependency	-0.03					
	(1.68)					
Areas w/ water depending & covering their needs.	2.04					
	(2.72)					
Falkenmark index (local water only)		2.01*				
		(1.04)				
Falkenmark index (including water from upstream)			2.24**			
			(0.97)			
Yearly Average Daily temperature (°C)				3.54***		
				(0.71)		
Temperature Amplitude (°C)					12.34***	
					(3.74)	
Yearly Precipitation - mm/yr						0.86
						(1.46)
Observations	10,272	10,272	10,272	10,272	8,252	10,272
Adjusted R-squared	0.46	0.46	0.46	0.46	0.40	0.46

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Least squares estimates. Standard errors clustered by dyad in parentheses. All specifications include bilateral × basin and year fixed effects. *Cooperation* is a dummy which is 1 when there is at least one event of cooperation within the year between the two countries (multiplied by 100).

Table 12: Intensity of the cooperation: IRCC > 2

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. var.			Nb. of Cooperation Events			
Areas w/o water dependency	0.01					
	(0.01)					
Areas w/ water depending & covering their needs.	-0.03*					
	(0.01)					
Falkenmark index (local water only)		0.03***				
		(0.01)				
Falkenmark index (including water from upstream)			0.03***			
			(0.01)			
Yearly Average Daily temperature - Kelvin				0.03***		
				(0.01)		
Temperature Amplitude					0.05**	
					(0.03)	
Yearly Precipitation - mm/yr						0.03***
						(0.01)
Observations	10,325	10,325	10,325	10,325	8,269	10,325
Adjusted R-squared	0.41	0.42	0.42	0.42	0.40	0.41

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Least squares estimates. Standard errors clustered by dyad in parentheses. All specifications include bilateral × basin and year fixed effects. *Cooperation* is a dummy which is 1 when there is at least one event of cooperation with IRCC > 2, within the year between the two countries (multiplied by 100).

Table 13: Conflict Incidence: Baseline results

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. var.			Conflict (yes/no)			
Areas w/o water dependency	-0.43					
	(0.62)					
Areas w/ water depending & covering their needs.	-0.41					
	(0.37)					
Falkenmark index (local water only)		0.07				
		(0.22)				
Falkenmark index (including water from upstream)			0.14			
			(0.25)			
Yearly Average Daily temperature (°C)				0.14		
				(0.19)		
Temperature Amplitude					0.41	
					(0.94)	
Yearly Precipitation - mm/yr						0.31
						(0.44)
Observations	9,159	9,159	9,159	9,159	7,307	9,159
Adjusted R-squared	0.25	0.25	0.25	0.25	0.17	0.25

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%. Least squares estimates. Standard errors clustered by dyad in parentheses. All specifications include bilateral × basin and year fixed effects. *Conflict* is a dummy which is 1 when there is at least one event of cooperation within the year between the two countries (multiplied by 100).

8 Appendix: Additional information on data

8.1 Data on IRCC

Table 14: International Rivers Cooperation and Conflict (IRCC) scale

Value	Type
6	alliance
5	official support
4	agreement/commitment
3	agreement of low scale
2	verbal support
1	minor official exchanges, talks or policy expressions
0	neutral acts
-1	mild verbal expressions displaying discord in interaction
-2	strong verbal expressions displaying hostility in interaction
-3	hostile actions
-4	breaking diplomatic relations
-5	any violent acts (that do not yet constitute a war)
-6	Violent conflict, formal declaration of war

Notes: Data from the International Rivers Cooperation and Conflict.

8.2 Data on economic, demographic and political conditions

GDP per capita. GDP is measured at current prices (Gleditsch, 2002)
Institutional quality. Information on institutional quality come from the *International Country Risk Guide* (ICRG). ICRG collects political, financial and economics data to assess a yearly country risk. Data are available since 1984. ICRG is considered in the literature in political science and economics as a proxy of the institutional quality.
Polity score. Data on autocracy/democracy come from *Polity IV project dataset* (Marshall and Jaggers, 2013). It is most widely used dataset to explore regime changes, evolution of autocracy/democracy. Variable is scaler from -10 (autocracy) to +10 (democracy).
Oil and Gas net exporter. This variable is build thanks to data from Ross (2013). He has developed a dataset with information on oil and gas production, prices, exports and net-exports. We define a yearly dummy variable coded 1 if country is oil or gas net exporter (per capita, constant 2000 dollar).
Agriculture (% GDP). It represents the value added of the agriculture sector (% GDP). Data come from the World Development Indicator and are available from 1960 to 2012.
Rural population (%). It represents the share of rural population. Data come from the World Development Indicator.

Table 15: Economic, Demographic and Political Conditions: Summary Statistics

	Min	Max	S.D.	Mean	Obs.
GDP/per cap	5.71	11.26	1.22	8.33	9,566
Institutional quality	0.18	1	0.18	0.53	7,337
Polity score	-9.5	10	5.38	3.30	9,427
Oil/Gas, net exporter	0	1	0.50	0.44	10,329
Agriculture (% GDP)	0.60	70.22	13.45	17.97	9,342
Rural population (%)	8.05	90.94	19.67	48.60	10,049

Notes: The variables displayed in this table are dyad averages.

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