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Research paper

Assessment of transboundary river basins for potential hydro-political tensions

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ABSTRACT

This paper presents a systematic, global assessment of transboundary watersheds that identifies regions more likely to experience hydro-political tensions over the next decade and beyond based upon environmental, political, and economic indicators. The development of new water infrastructure in transboundary basins can strain relationships among fellow riparians as the impacts of new dams and diversions are felt across borders. Formal arrangements governing transboundary river basins, such as international water treaties and river basin organizations, provide a framework for dialogue and negotiation, thus contributing to assuaging potential disputes. Our study examines these two issues in tandem – the stresses inherent in development and the mitigating impact of institutions – and maps the risk of potential hydro-political tensions that exist where basins may be ill-equipped to deal with transboundary disputes triggered by the construction of new dams and diversions. We also consider several factors that could exacerbate those hydropolitical tensions in the near future, including changes in terrestrial water storage, projected changes in water variability, per capita gross national income, domestic and international armed conflicts, and recent history of disputes over transboundary waters. The study points to the vulnerability of several basins in Southeast Asia, South Asia, Central America, the northern part of the South American continent, the southern Balkans as well as in different parts of Africa, where new water infrastructure is being built or planned, but formal transboundary arrangements are absent. Moreover, in some of these regions there is a concomitance of several political, environmental and socio-economic factors that could exacerbate hydropolitical tensions. This study contributes to the understanding of how the recent proliferation of development accompanied with unfavourable socio-economic and environmental indicators may influence global hydropolitical resilience.

1. Introduction

Anticipating where tensions or conflicts over transboundary waters may arise or escalate in the short- or mid-term is key to guide policy interventions and focus capacity-building efforts where they are more needed. The search for hotspots of hydropolitical tension can be framed as an assessment of “hydropolitical vulnerability”, which is associated with the risk of political dispute over shared water systems (Wolf, 2007).

Identifying areas of potential transboundary tensions first requires understanding the nature and frequency of past disputes, through in-depth case studies and global or regional inventories of instances of conflict and cooperation. The first attempt to provide a global overview of interactions over water between riparian countries produced the International Water Event Database (IWED, Wolf et al, 2003b; De Stefano et al., 2010), which reports cooperative and conflictive interactions over diverse water issues for the period 1948–2008. The International River Basin Conflict and Cooperation (IRCC), developed by Kalbhenn and Bernauer (2012), utilizes an approach similar to the IWED by using a modified coding system and covers the period 1997–2007. Finally, the Issue Correlates of War – River Claims dataset records explicit contention between two or more nation-states over the use or abuse of a specific river for the period 1900–2001 in the Western Hemisphere, Northern and Western Europe, and the Middle East (Hensel et al., 2008). These inventories provide global overview of transboundary tensions and cooperation, but as any global dataset, provide a simplified picture of the complex reality of disputes. Starting from the idea that the “the absence of war does not mean the absence of

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conflict" (Zeitoun and Warner, 2006), Zeitoun and Mirumachi (2008) proposed a two-dimensional matrix to classify interactions (Transboundary Waters Interaction Nexus) that underscores the dual nature of interactions (conflict and cooperation) over transboundary waters, and applied it to a selected number of basins. Similarly, Watson (2015) cites Galtung (1969) to distinguish between "negative peace", meant as the absence of physical, direct violence, and "positive peace", defined as the absence of structural violence. Based on this important distinction and the experience of Wolf et al. (2003b), Watson (2015) builds and tests in the Mekong basin a coding system (Integrated Basins at Risk, iBAR) that considers also inequalities and injustices within the basin.

In parallel to the development of these inventories, many authors have explored what can contribute to conflict in transboundary basins, considering issues such as the saliency of the river (Hensel et al., 2008); water availability (e.g. Toset et al., 2000; Furlong et al., 2006; Gleditsch et al., 2006); climate change (Nordås and Gleditsch, 2007; Gleditsch, 2012); peacefulness of riparian relationships (Brochmann and Gleditsch, 2012); level of democracy (Brochmann and Hensel, 2009; Brochmann and Gleditsch, 2012); commercial trade (Espey and Towfique, 2004; Brochmann and Hensel, 2009; Tir and Ackerman, 2009; Dinar et al., 2015); upstream-downstream relationships (Munia et al., 2016); the existence of transboundary treaties (Brochmann, 2012; Wolf et al., 2003a; Tir and Stinnett, 2012) or the specific design of international water agreements (Dinar et al., 2015). These studies use theoretical arguments or historical evidence to establish causal links between conflicts and factors potentially conducive to tensions over water, which is the first but necessary step to identify of future potential tensions.

Forward-looking analyses of international river basin conflict and cooperation at a global scale are limited in number and challenging, both methodologically and in terms of data availability. The TFDD Basins at Risk (BAR) project undertook for the first time a systematic global study of the causes of water conflict and identified in a qualitative way 29 basins to be at potential risk of conflict (Wolf et al., 2003b). More recently Bernauer and Böhmelt (2014), applied prediction and forecasting methods to identify river basins that are prone to conflict or cooperation. Finally, De Stefano et al. (2012) identified transboundary basins at risk of hydropolitical tension stemming from the combination of low institutional resilience to water variability with high historic or projected variability regimes due to climate change.

This paper aims to contribute those type of analyses by identifying international basins that could experience hydropolitical tensions due to the stress associated with the construction of dams and water diversions and exacerbated by other contextual factors. Our approach includes: a) A method for determining areas of potential risk of future dispute by mapping new or planned water infrastructure development and examining formal institutional capacity in these locations; and b) Integration of additional environmental, political, and economic indicators known to increase tensions in transboundary basins. Our results identify which regions and basins are most likely to experience hydropolitical disputes, and may be used to focus more in-depth analysis in potential hotspots and to inform efforts aimed at mitigating potential water conflicts between riparian nations.

2. River basin development and institutional resilience

In the context of transboundary relations, past research suggests that the most indicative variables for conflict reflect rapid or extreme change to physical or institutional systems within a basin in absence of transboundary institutional mechanisms able to manage the effects of that change (Wolf et al., 2003b).

Dams and water infrastructure help manage water variability − providing water in times of drought or dampening the effects of floods − but can also substantially change the hydrological function of the basin where they are built. Thus dams and water infrastructure can become significant sources of transboundary water disputes, from when they are first conceived until the end of their life cycle (Yoffe et al., 2003; De Stefano et al., 2010; Gleick 1993; Eckstein 1995; Eshchanov et al., 2011; Gleick and Heberger 2013). After a slowdown in the 1990s, the world has recently seen a resurgence in new water development, and many opportunities for this development lay in transboundary river basins (McCartney, 2007; Wang et al., 2014). These new developments underscore the policy relevance of mapping and monitoring where new dams and water diversions are being built or are planned.

The construction of large dams in upstream riparians without an agreement in place was found to be one of the strongest indicators of a basin's potential hydropolitical tension (Wolf et al., 2003b). This is evident in the Nile Basin, where the government of Ethiopia's construction of the Grand Ethiopian Renaissance Dam has been occurring without an agreement with downstream Egypt. News of its construction was greeted within Egypt by violent protests and strong rhetoric from Egyptian politicians (Gebreluel, 2014). At the same time, dams built with mechanisms for benefit-sharing between riparian nations can be positive for cooperation (Gryzbowski et al., 2009). However, conflict and lengthy renegotiations may occur at a later stage if negative environmental and social effects of these dams are neglected in initial cooperative frameworks (Hensengerth et al., 2012).

Building institutional capacity, in the form of treaties and river basin organizations, is considered to contribute to the decrease of the likelihood of hydropolitical conflict (Wolf et al., 2003a,b; Yoffe et al., 2004; De Stefano et al., 2012; Tir and Stinnett, 2012; Brochmann, 2012). Moreover, transboundary water agreements can include mechanisms like flow variability or data sharing provisions (Gerlak et al., 2011) that reduce uncertainty and increase flexibility, thus boosting the overall adaptive capacity of the basin (Milman et al., 2013). Yet, the mere presence of treaties does not necessarily indicate hydropolitical resilience (Zeitoun and Warner, 2006), nor does the presence of agreements preclude the absence of conflict. Inherent weaknesses of certain consent-building relations in water also exist. For example, riparians can exploit treaties because they are not easily enforceable or are structured to reflect (or exacerbate) existing inequalities between riparians, which leads to non-signatory riparians not participating (Zeitoun and Warner, 2006). A rich literature critical of the presumed relationship between treaties and cooperation has developed led by the London Water Research Group. Members of which have made the important case that treaties can not only solidify power imbalances between actors, but they can lock out public participation, and may even be a source of conflict themselves (see, for example Zeitoun and Mirumachi, 2008; Zeitoun et al., 2011). It may also be the parties engaged in cooperation, rather than the treaty or institution's content or presence, which may be at the heart of a successful agreement (Chasek et al., 2006). Treaty presence may also falsely imply the degree to which transboundary waters are effectively managed (Zawahri, 2008). In Africa, of the 153 agreements identified by Lautze and Giordano (2005), only 108 were considered substantive regarding transboundary water resources issues, while others were either never implemented in practice or are no longer enforced.

While the presence of a treaty is no guarantee of constructive relations and a number of circumstances have been found to contribute transboundary cooperation (Varady et al., 2013), treaties can provide a starting point for dialogue among riparians (Tir and Stinnett, 2012). Significantly, the "proportion of transboundary basin area with an operational arrangement for water cooperation" (Indicator 6.5.2) is being discussed to be an indicator of the achievement of the Sustainable Development Goal Target 6.5 ("By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate"). While the methodology for measuring this indicator is still being developed (UN-Water, 2016), it is clear both that treaties and River Basin Organizations (RBOs) will be a central gage of transboundary cooperation. Institutional capacity in a basin is generally bolstered by effective RBOs, resilient treaties, and generally strong geopolitical relations. Milman et al. (2013) use the existence of a treaty and of a RBO as indicators of transboundary adaptive capacity, as they represent formal commitments among riparians and the designation of an entity to consider transboundary aspects of the basin. The importance of RBOs has been conceptualized and documented most thoroughly by Schmeier (2012) and Schmeier et al. (2016), who also note that RBOs, like treaties, do not, in and of themselves, ensure cooperation unless they have multiple attributes and characteristics.

Despite the reality that every treaty is complex and unique, certain characteristics have been shown to improve treaty effectiveness: flexible management structure, clear and flexible allocating criteria, equitable distribution of benefits, detailed conflict resolution mechanisms (Giordano and Wolf, 2003), and mechanisms for increasing resilience towards water variability (Drieschova et al., 2008; De Stefano et al., 2012), such as flexible but specific water allocation mechanisms (Dinar et al., 2015). Institutional models should also make explicit provision for institutional learning and change (Meinzen-Dick, 2007). Additionally, treaties that include a direct enforcement measure, an adaptability mechanism, and a self-enforcement clause present higher levels of cooperation relative to those that do not have such provisions (Dinar et al., 2015).

3. Factors potentially exacerbating tensions

A range of factors, including high population growth, urbanization, increasing water pollution, over-abstraction of groundwater, climate change and water-related disasters, have been reported to be likely to contribute to increase tension among riparian countries in the future (Asian Development Bank, 2013), suggesting that several factors might strain transboundary relations besides new water developments. For instance studies have argued that a basin's size, particularly in the context of national water scarcity, may increase the potential for conflict escalation (Ashton, 2002; Sneddon, 2002). Regarding riparian configuration, Gleditsch et al. (2006) found that a shared basin is positively and significantly correlated to conflict, while a river that creates a boundary between countries is not.

A large body of literature has focused on the relationships between water scarcity, water variability, or climate change and transboundary conflict. Projected climate trends suggest increased hydrologic variability (Vörösmarty et al., 2000; Arnell, 2004; Kundzewicz et al., 2008; Arnell and Gosling, 2013), which could potentially increase future tension as climatic variability and has been linked with higher likelihoods of conflict (e.g. Hendrix and Salehyan, 2012; Raleigh and Kniveton, 2012) and conflict intensity (Papaioannou, 2016). Declines (or the threat of declines) in water quality due to pollution may also aggravate relationships, such as when Ukraine's government discussed building the Bystroe Canal in the Danube delta, despite the objections of the government of Romania and the European Union (Oregon State University, 2017). Upstream-induced water stress, even if not a major cause of conflict, has been found to play a role in the nature of transboundary relations (Munia et al., 2016). Coupled with increased water variability due to climate change, water scarcity is also becoming more severe, leading to continued depletions in groundwater (Wada et al., 2010). For example, increased groundwater abstraction in the Tigris-Euphrates Basin in response to drought and declining surface water availability compounded by upstream management by riparian states was measured using satellite measurements of terrestrial water storage (Voss et al., 2013; Gleick, 2014). With highly limited surface water availability, downstream users often turn to over pumping of groundwater reserves, leading to growing political and economic instability, thereby increasing the likelihood of conflict (Gleick, 2014).

While the effects of scarcity and/or variability could exacerbate tensions between riparians, neither scarcity nor variability determine whether conflict over water will arise. Indeed, other factors, including political and economic factors, are more likely to determine whether violent conflict breaks out including over water (Raleigh and Urdal, 2007; Tir and Stinnett, 2012; Bernauer and Siegfried, 2012). The analysis of the history of conflict and cooperation over water in transboundary basins suggests that some political, socioeconomic and physical circumstances may exacerbate the risk of hydropolitical tensions due to basin development in the absence of institutional capacity (Wolf, 2003b). Changing sovereignty over the resources is one of these circumstances, as international resource conflict is most likely to emerge where jurisdiction is not well defined or non-existent, institutional regimes in place are destroyed by political change, and/or the change in the resource outpaces institutional capacity to be resilient towards the change (Giordano et al., 2005). In this context, the presence of armed conflicts involving minorities within a given country could point to regions more likely to see the transformation and/or creation of new borders in the future. Other factors that might exacerbate tensions between riparians include the occurrence of armed conflicts (both between and within states) (Gleditsch et al., 2006), a history of conflictive relationships between riparians over water, and low economic level (Kukk and Deese, 1996; Toset et al., 2000), which decreases the capacity of the society to adapt (Engle and Lemos, 2010). Inter-state water conflicts are more likely to erupt in regions with low social stability (Giordano et al., 2002) and higher rates of civil war occur in countries with lower gross national product per capita (Hauge and Ellingsen, 1998; Blattman and Miguel 2010).

While these factors can play a role individually, conflict is usually a concomitance of several factors (Munia et al., 2016). In other words, no single parameter can be used as a strong indicator of water disputes, as it is rather a set of converging factors that can increase the likelihood of tensions. Within those converging factors, our work identifies sets of indicators that suggest basin settings conducive to conflict. By pairing those indicators that point to rapid changes within a basin, whether biophysical or geopolitical, with those that suggest institutional capacity to absorb that change, an empirically driven methodology can be developed to anticipate basins more or less at risk of conflict in the near future.

4. Methodology

In order to assess basins with settings that are more or less conducive to conflict at a global scale, we focused on the relationship between the rate of change within a basin, and the institutional capacity to absorb that change. Taking a clarification from Bernauer and Siegfried (2012) as a starting point, in this paper we define "conflict", "dispute" or "tension" as "conflictual interactions between states that may range from mutual accusations and diplomatic tensions all the way to what popular quantitative datasets define as militarized interstate disputes" over water.

Drawing from methods used in the Transboundary Waters Assessment Programme (TWAP) (UNEP-DHI and UNEP, 2016), this research followed a sequence of four steps to determine which basins are at the highest risk of hydropolitical tension in the next 5–10 years through a multi-criteria analysis, based on the exacerbating impacts of water development and change as moderated by the mitigating impacts of institutional capacity. First, we made an inventory of ongoing and planned development of water infrastructure in transboundary basins. Second, we mapped the presence of several formal institutional mechanisms that can contribute create institutional resilience to tensions associated with river basin development. Third, we combined both to identify which basins may be ill-equipped to deal with transboundary disputes triggered by new water infrastructure and that, for this reason, are at potential risk of hydropolitical tension. Finally, we mapped six factors that are likely to exacerbate those tensions and used them as an additional layer of information to understand where potential hydro-political tension may lay in the near future. The individual components of the analysis sequence are described in greater detail subsequently.

The analysis was conducted at the basin-country unit (BCU) level. A BCU is defined as the portion of a riparian country's land area that is within a certain transboundary river basin. For instance, the Tagus River Basin has two BCUs: the land area in Spain that is within the Tagus River drainage, and the land area in Portugal. The results were also aggregated to obtain basin scores. The analysis was undertaken in the 286 transboundary basins and 795 BCUs listed in the Transboundary Freshwater Dispute Database (http://gis.nacse.org/tfdd/index.php) as of December 2014.

4.1. Mapping water infrastructure and institutional resilience

Stress on transboundary relations due to new developments in water infrastructure was estimated using Petersen-Perlman's dataset (2016), which catalogued diversions projected to divert quantities exceeding 100,000 $m^3\,yr^{-1}$ and dams in excess of 10 Megawatts in capacity that were under construction, proposed, or planned as of July 2014. Petersen-Perlman's dataset (2016) used data from websites of organizations that have historically funded dam construction (e.g. World Bank), International Rivers, the United Nations Framework Convention on Climate Change's Clean Development Mechanisms (UNFCCC, 2014), and other sources. In addition to cataloguing new water infrastructure development, the analysis also accounted for potential downstream stresses that development could bring, by labelling BCUs as "high hazard" (H) if potential new water infrastructure development could impact them, and "low hazard" (L) if there was no new development (Table 1).

Calculation of institutional resilience, which expresses the capacity of each BCU to deal with tensions associated with the development of new dams and water-diversion schemes, consists of five components (Table 2), which were originally developed by De Stefano et al. (2012) to analyse institutional resilience to climate-driven water variability. Yet, these components are relevant also when assessing institutional resilience to new infrastructure. Three of them − a) presence of a water treaty, b) presence of a river basin organization and c) existence of conflict resolution mechanisms − contribute to creating a general framework for cooperation within a transboundary basin. The other two − d) water allocation mechanisms and e) provisions to manage flow variability − are particularly relevant to address tensions that could be triggered by the construction of a water infrastructure. Institutional capacity data was acquired from De Stefano et al. (2012). Additionally, data was obtained from Schmeier (2017) on conflict resolution mechanisms present within international river basin organizations. BCUs were assigned points (zero to five) for each component present (Table 2). After points were assigned, BCUs were then grouped into three levels of institutional vulnerability: "low" (institutional resilience scores of four or five), "medium" (scores of two or three), and "high" (scores of zero and one).

4.2. Mapping key exacerbating factors

Guided by the availability of global data and buttressed by the literature on transboundary conflict and cooperation, we considered six factors that could exacerbate transboundary hydropolitical tension (Table 3): a) locations with high present or projected increased water variability due to climate change; b) recent depletion trends in water reserves; c) the presence of armed conflicts within a state; d) the presence of armed conflicts between states; e) recent unfriendly interactions between states over water; and f) low gross national income per capita. Exacerbating factors were computed at a BCU level by adding the resulting six scores together to obtain the overall number of exacerbating factors by BCU.

Table 1
BCU Hazard Classification due to Water Developments.

Presence of Large Dam and Water Diversion Projects	Hazard Score
No presence (in the BCU or upstream of it)	1 – LOW
Presence (in the BCU or upstream of it)	3 − HIGH

Table 2
Components to assess institutional resilience.

Treaty-RBO component	Possible value
At least one water treaty	0/1
At least one treaty with an allocation mechanism	0/1
At least one treaty with a flow variability management mechanism	0/1
At least one treaty with a conflict resolution mechanism	0/1
At least one river basin organization	0/1
Total possible value for a basin-country unit	0 to 5

Factor "a", the factor measuring high or increased climate-driven water variability, was calculated using the Coefficient of Variation (CV) of annual runoff, with 1971–2000 as the baseline and climate change projections for 2021–2050 (representing 2030) (Schewe et al., 2014). The CV absolute values for both the baseline and projection periods were grouped into three categories: "low" ($CV < 0.25$), "medium" ($0.25 \le CV \le 0.75$), and "high" ($CV > 0.75$) variability. BCUs with high CV absolute values for both the baseline and projection periods were assigned a final water variability hazard score of 1. BCUs with a higher CV for the projection period compared to the baseline period also were assigned a final water variability hazard score of 1.

Factor "b", measuring recent depletions in water reserves, was calculated using eleven years of monthly terrestrial water storage anomalies (TWSA) from GRACE RL-05 satellite data (Landerer and Swenson, 2012; Swenson and Wahr, 2006) located on NASA's Tellus website (http://grace.jpl.nasa.gov). Conceptually TWSA shows changes in the vertical sum of water in storage as snow, surface water, soil moisture, and groundwater in and across the earth's surface (Sproles et al., 2015). After the processing of GRACE data, the data signal is smoothed using data from adjacent areas. The analysis used 127 months of GRACE data from the time period of January 2003–July 2013, calculating the Sen's-slope (Sen, 1968) at 1° resolution across all of Earth. A Sen's-slope reflects the median slope of the overall data series, without being over-influenced by data points that are outliers. The Sen's-slope values were classified into two groups: stable and positive (−0.1–0.39, excluding −0.1) and negative (−0.1 to −0.94). The hazard score threshold is −0.1.

Factor "c", the presence of armed conflicts within a state, was calculated using data collected by the Minorities at Risk project (MAR, 2009). Using the conflict severity values within the MAR database (*FACTSEV1* variable), all countries having a value of 3 or more were scored as having an intrastate conflict score of 1. If a country had multiple BCUs within its borders, all of the BCUs were assigned the same intrastate conflict value.

Factor "d", the presence of armed conflicts between states, was calculated using data from the UCDP/PRIO Armed Conflict Dataset (v.4-2013, 1946–2012). Incidents were selected from the time period of 2000–2012 and were limited to those in which both sides of the conflict included a government, either in a primary or secondary (supporting) role (Themnér and Wallensteen, 2012).

Factor "e", recent unfriendly interactions over water, was calculated using data from the TFDD Water Events Database (Oregon State University, 2017). Each event from the database has a score from the Basins at Risk scale, with negative values indicating events that were disputes, and positive values indicating cooperative events. Each BCU was assigned a score based on the average value for all events occurring within a BCU between 2000 and 2008 (De Stefano et al., 2010). If the BCU average event score was negative, a hazard value of 1 was assigned.

Finally, factor "f", low gross income per capita, was calculated with

Table 3
Construction of hazard score due to the presence of tension-exacerbating factors.

Exacerbating factor→	a Water variability	b Water availability	c Intrastate conflict	d Interstate conflict	e Recent water events	f Per capita income level
Hazard Score ↓	Projected Coefficient of Variation (CV)	Sen's Slope (2003–2013)	Conflict severity value (2009)	Armed Conflict (2000–2013)	BAR scale Average (2000–2008)	GNI per capita, (2008–2012 Avg, current US$)
0	CV: No change (Med or Low) OR decrease	Stable or Positive (> −0.1–0.39)	< 3	No occurrence	≥0	≥$1 035
1	CV: High present and future OR increase	Negative (≤ −0.1–−0.94)	≥3	Occurrence	< 0	< $1 035

Gross National Income (GNI) per capita, Atlas method (current USD) (World Bank, 2017), averaged for each country over the most recent five years available (2008–2012). If the average GNI of a BCU for this time period fell below the $1035 poverty threshold (World Bank, 2013), it was assigned a hazard value of 1.

4.3. Calculation of relative risk of potential hydropolitical tensions

Applying the definition of risk as a combination of both hazard and vulnerability (Blaikie et al., 1994), we combined the level of hazard due to new water resources infrastructure with the level of vulnerability due to gaps in relevant institutional arrangements to define the Relative Risk of Potential Hydropolitical Tensions (Table 4). The risk value was grouped into five relative risk categories based on the risk of new infrastructure and institutional capacity by BCU.

5. Results and discussion

5.1. Ongoing or planned infrastructure projects

The construction of 1416 new large dams and water diversions is on-going or planned in at least 57 basins worldwide (Fig. 1). The new dams are highly concentrated in very few BCUs: according to our data, 16 BCUs have 77% of the new dam construction occurring worldwide. Three BCUs have over 100 dams that are proposed, planned, or under construction: Ganges-Brahmaputra-Meghna-Nepal (183), Amazon-Brazil (155), and Ganges-Brahmaputra-Meghna-India (115). Observing the number by continent, Asia has the highest number of proposed, planned, and under construction dams in transboundary basins (807 dams), followed by South America (354), Europe (148), Africa (99), and North America (8). Regarding the frequency of projected dams in BCUs, all BCUs with projected and planned dam development in North America and most African BCUs have only 1–5 projected dams, while the frequency of dam development in BCUs in Asia, South America, and Europe is more varied (Fig. 2). Hotspots in the African continent can be found in Ethiopia, Lake Chad, and South Sudan. In Ethiopia there are plans for the construction of several new dams (International Rivers, 2010; African Development Bank, 2015). In the drainage basin of Lake Chad, feasibility studies on potential diverting works have been initiated or completed (LCBC, 2014).

Table 4
Relative Risk of Potential Hydropolitical Tension (defined by color scheme) (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

	1 – Low (Hazard)	3 – High (Hazard)
1 (Low Vulnerability)	1 (Very Low)	3 (Moderate)
2 (Med Vulnerability)	2 (Low)	6 (High)
3 (High Vulnerability)	3 (Moderate)	9 (Very high)

5.2. Institutional resilience

As explained earlier, the calculation of institutional resilience was based on the dataset used in De Stefano et al. (2012) and complemented with new data from Schmeier (2017) to add the presence of some RBOs and conflict resolution mechanisms that were not included in that study. As expected, the main trends of this indicator do not change substantially relative to De Stefano et al. (2012). Europe and North America present a high number of institutional components to support transboundary cooperation, while South America and Asia have many BCUs with a limited formal institutional capacity. Beyond the presence of a water treaty, conflict resolution is the most frequent component present in BCUs, while variability management is the least frequent one.

Beyond the calculation of the institutional resilience undertaken to estimate the potential risk for hydropolitical tensions, the dataset by De Stefano et al. (2012) was helpful to provide a first overview of the proposed Indicator 6.5.2 ("proportion of transboundary basin area with an operational arrangement for water cooperation") of Target 6.5 of the Sustainable Development Goals (Fig. 3). The methodology for this indicator (UN-Water, 2016) refers to both transboundary surface water catchments and transboundary aquifers, while here we focus only on surface waters. "Arrangement for water cooperation" is defined as "a bilateral or multilateral treaty, convention, agreement or other formal arrangement, such as memorandum of understanding) between riparian countries that provides a framework for cooperation on transboundary water management. Agreements or other kind of formal arrangements may be interstate, intergovernmental, interministerial, interagency or between regional authorities" (UN-Water, 2016). Assessing which arrangement can be considered as "operational" according to the methodology was out of the scope of this paper. Adapting the methodology described in UN-Water (2016), Fig. 3 was obtained by summing the surface area in a country of transboundary surface water catchments that are covered by at least one treaty or RBO and dividing the resulting area by the aggregate total area in a country of all transboundary basins. The result is expressed as percentage share.

5.3. Risk of hydropolitical tensions and exacerbating factors

The majority of international basins (160 of 286) were found to have a moderate risk of hydropolitical tension, whereas thirty-six basins were classified as having a "high" (14; Table 4) or "very high" (22) risk (Fig. 4; for the list of the thirty-six basins see Table 5). Those basins correspond to 27% of the area covered by shared river basins and 13% of the transboundary population, and are concentrated in the African and Asian continents, especially in Sub-Saharan Africa and in Central and Southeast Asia (Fig. 5a and b). Within Sub-Saharan Africa, there are plans underway for new dams in recently-formed South Sudan despite its lack of institutional capacity for transboundary water management. In Asia, China's government has been building many

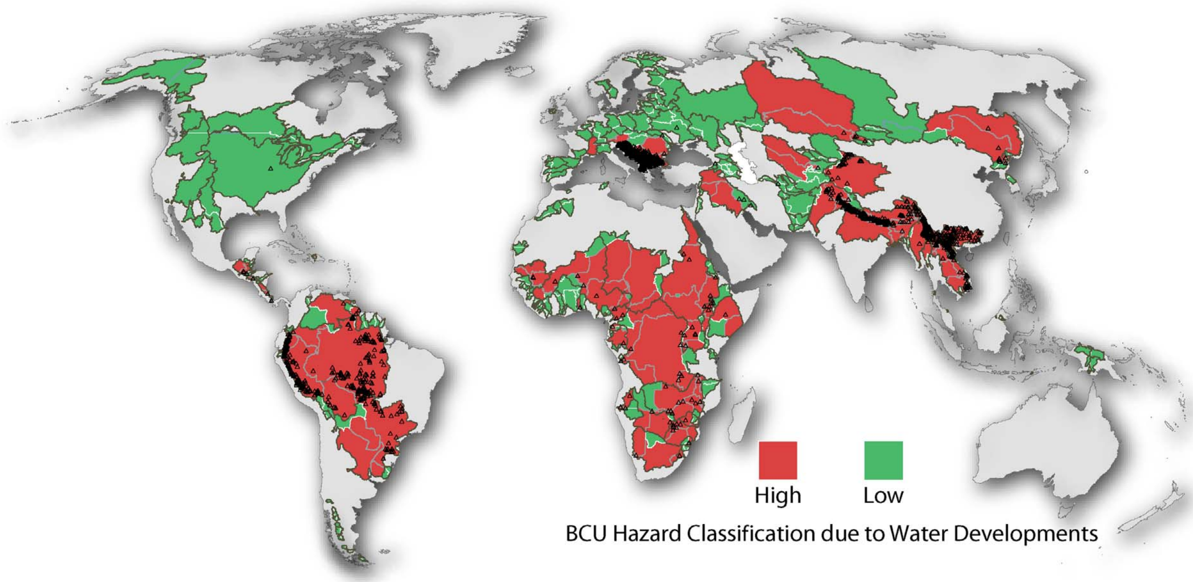

Fig. 1. Dam distribution in transboundary BCUs. Each diamond represents one dam.

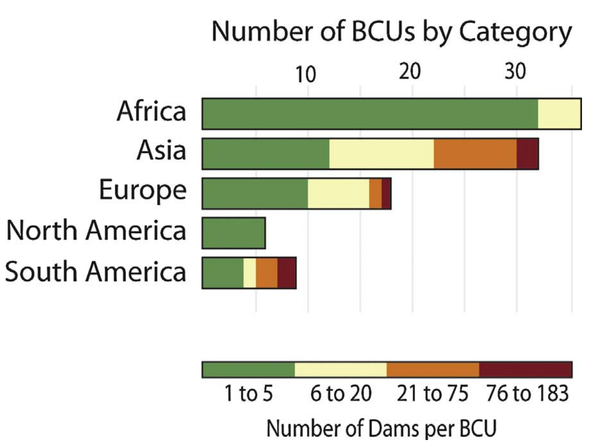

Fig. 2. Number of BCUs that have certain frequencies of proposed, planned, or under construction dams. The vast majority of BCUs have no new dam activity.

dams but has been reluctant up to this point to formally participate within multilateral transboundary agreements, instead engaging bilaterally with each of its neighbors.

New water infrastructure being constructed in areas with limited formal transboundary agreements is also located within the headwaters of transboundary basins of Central and South America (Fig. 5d). Within South America, institutional capacity in the form of treaties and RBOs could be expanded and improved in the Amazon and Orinoco basins, as many new dams are being built within each basin. In contrast, Northern America and Europe appear to be less at risk of hydropolitical tensions (Fig. 5c and e), with the southern Balkans being an exception. Within the southern Balkans, many water infrastructure projects are planned or under construction without well-developed institutions installed.

In our analysis of six exacerbating factors to hydropolitical tension, 87 BCUs have two factors present, 20 have three factors, and one has five factors (the Ethiopian portion of the Awash river basin). These BCUs are mostly located within Central and Eastern Africa, the Middle East, and Central, South, and Southeast Asia. Within Central and Eastern Africa, the most present factors include those related to low GNI per capita, the presence of inter- and intra-state armed conflicts, and high water variability. The Middle East mainly has exacerbating factors linked to international tensions (both generally and over water), water reserve depletions, and high water variability. Central Asia exhibits factors of armed conflicts, low GNI per capita, and water variability, exacerbating the task of riparians managing tensions associated with new dams and water diversions.

The comparison of the maps of risk of hydropolitical tension and exacerbating factors adds a new layer of interpretation to the results. For instance, maps on Fig. 5a reveal that Eastern and Central Africa have a moderate to high risk of transboundary tension over new infrastructure that could be fueled by a high concentration of exacerbating circumstances. Similarly, in the Tigris and Euphrates region potential risk of hydropolitical tension appears to be moderate to high and the map of exacerbating factors reveals that there are also several conditions that are likely to strain transboundary relations (Fig. 5b). In other regions, considering only the hydropolitical tension map could lead to underestimate the potential for transboundary dispute. This is the case of Central Asia, where in some BCUs have a moderate risk of transboundary tension but at the same time present several environmental, political and socioeconomic circumstances that could increase pressure on transboundary relations over new water infrastructure.

The results presented here have fairly noticeable differences compared to previous predictive basin risk analysis studies that were global in scale (Wolf et al., 2003b; De Stefano et al., 2012; Bernauer and Böhmelt, 2014). Of the 36 basins identified as having high or very high risk of future conflict in this study, only eight appear in both Wolf et al. (2003b) and in this study and only five basins are listed in both Bernauer and Böhmelt's list and ours (Table 6). What's more, only one basin (Ob) appears in all three studies. This is most likely due to different indicators being used to predict future conflict, and to changes in institutional capacity and other factors that have occurred over time in the transboundary basins. Though the factors used in Wolf et al. (2003b) were similar to the factors in this study, significant differences remain. For instance, the 2003 study focuses more on the presence (or lack thereof) of institutional capacity, and we note both the bolstering of institutional capacity in many identified basins, particularly in Southern Africa, as well as the fact that our study examines the institutional resilience of BCUs to withstand tension. Also, the list of proposed and/or planned water infrastructure projects has evolved since the 2003 study. Bernauer and Böhmelt's approach used an explanatory model to test the ability to predict and forecast basins at risk of future conflict. While using a predictive model certainly holds promise, our study goes beyond both Wolf et al.'s and Bernauer and Böhmelt's analyses by using different factors and more up-to-date

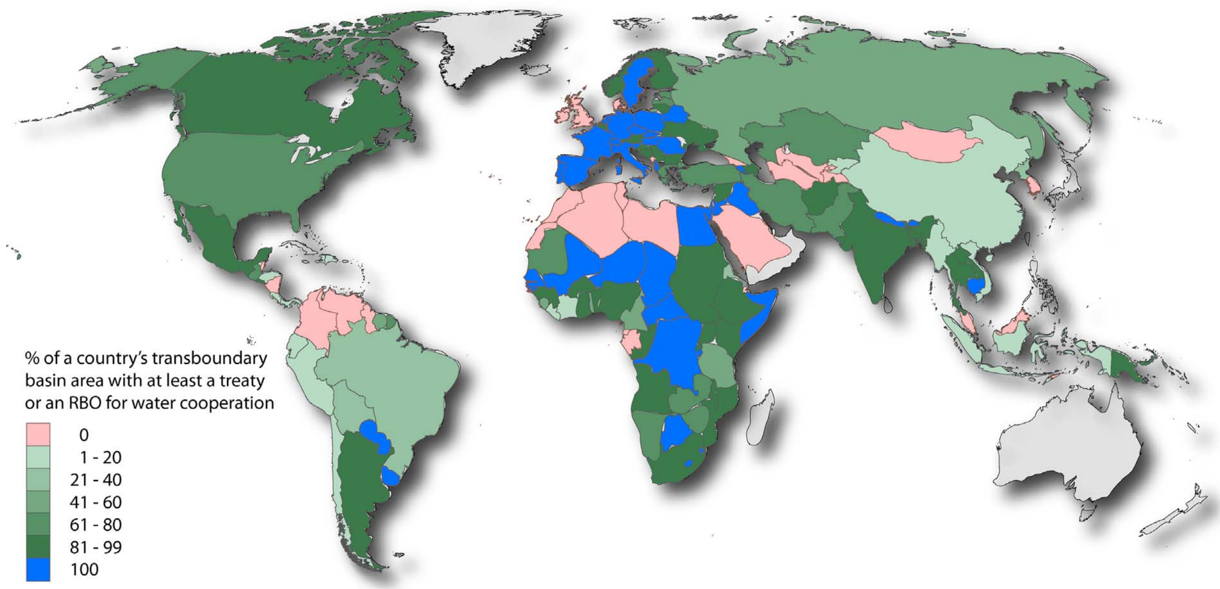

Fig. 3. Percentage of a country's transboundary basin area with at least a treaty or an RBO for water cooperation. Based on the proposed methodology for Indicator 6.5.2 of Target 6.5 of the Sustainable Development Goals (UN-Water, 2016).

information, particularly regarding locations of ongoing or planned water infrastructure projects. De Stefano et al.'s study focused on water variability and institutional resilience to climate change, thus not considering the stress generated by basin development and other exacerbating factors.

Several considerations should be kept in mind in the interpretation of the results of this global study. First, these findings are not meant to be interpreted as deterministic. Instead, given the scale of this study, the results at best can suggest basins that could be further analyzed. Dynamics at a basin scale and below are strongly nuanced and site specific, so any study utilizing global indicators can, at best, point to areas that warrant closer investigation. The Columbia Basin between the US and Canada, for example, whose treaty is held up as one of the most resilient and advanced agreements in the world, does not include a functioning River Basin Organization, for which it would score lower in our scale. Since its implementation in 1964, it has also mostly ignored tribal and environmental concerns, neither of which would be captured here at all. Similarly, Petersen-Perlman's (2016) comparative analysis of hydropolitical resilience of transboundary basins at both a global scale and within the Zambezi River Basin found that while the Zambezi Basin may be perceived as having higher political and physical resilience through a global analysis, the details found at the basin scale may not match the larger story at hand.

Second, our results evaluated the presence or absence of institutional capacity through international treaties and RBO agreements. The mere presence of these institutions does not guarantee effective enforcement, thus leaving the possibility for a BCU or river basin to have all the formal institutional mechanisms present but still unable to effectively manage conflicts that arise from new water infrastructure development. If this is the case within a certain BCU, this assessment can be used as a tool by policy-makers as to where efforts should be targeted, whether that is through improving the design of existing provisions, implementing existing provisions, or identifying and treating root causes of tensions between states. Our results also do not

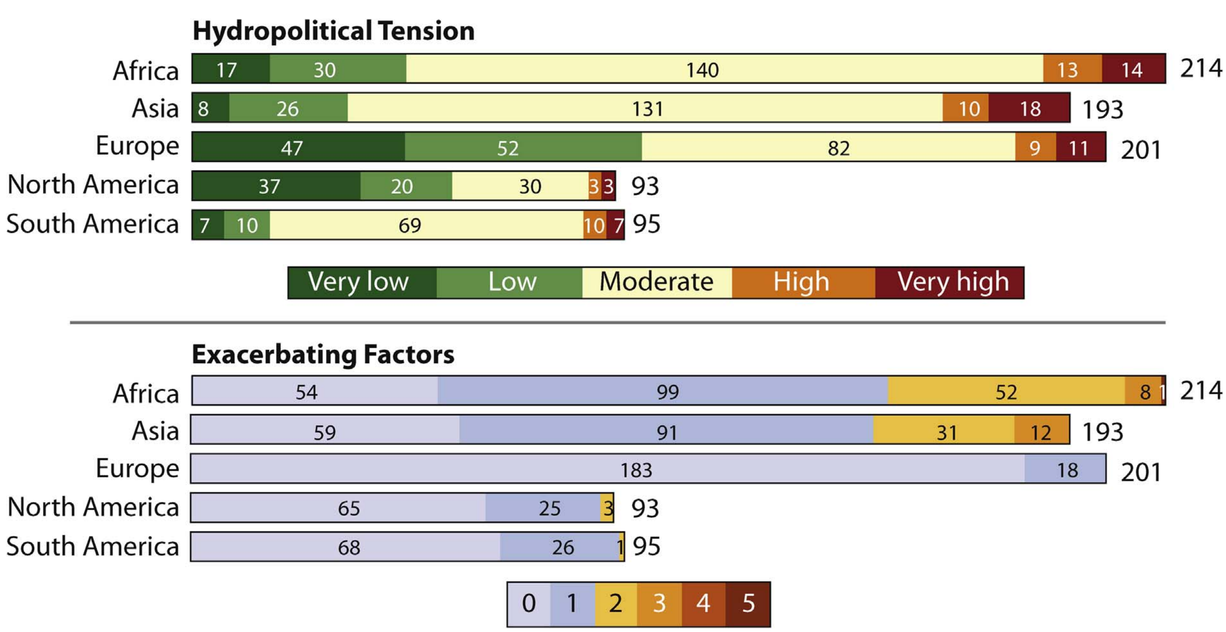

Fig. 4. Count of BCUs in each category of risk of hydropolitical tension.

Table 5
Basins at very high risk of potential hydropolitical tension. Population, runoff and discharge data: source UNEP-DHI and UNEP (2016).

Basin	Riparian Countries	Continent	Population [000′]	Runoff [mm/year]	Discharge [km^3/year]
Bei Jiang/Hsi	CHN, VNM	Asia.	77098	726	291.06
Benito/Ntem	CMR, GAB, GNQ	Africa.	657	1617	71.67
Ca/Song-Koi	LAO, VNM	Asia.	2741	761	20.73
Chiriqui	CRI, PAN	North America	90	2459	3.45
Drin	ALB, MFD, MNE, SRB	Europe	1766	869	15.03
Irrawaddy	CHN, IND, MMR	Asia	28583	1470	551.76
Krka	BIH, HRV	Europe	59	747	1.86
Lake Turkana	ETH, KEN, SSD, UGA	Africa	11733	369	63.83
Ma	LAO, VNM	Asia	2985	763	22.51
Mira	COL, ECU	South America	625	1034	10.82
Mono	BEN, TGO	Africa	2159	328	7.87
Neretva	BIH, HRV	Europe	633	1047	7.13
Ogooue	CMR, COG, GAB, GNQ	Africa	768	1447	310.05
Red/Song Hong	CHN, LAO, VNM	Asia	17864	766	107.18
Sabi	MOZ, ZWE	Africa	3428	135	13.80
Saigon	KHM, VNM	Asia	10911	1158	34.32
Salween	CHN, MMR, THA	Asia	7851	662	175.70
Sanaga	CAF, CMR, NGA	Africa	3443	1213	50.18
San Juan	CRI, NIC	North America	5057	647	86.15
Tarim	AFG, CHN, KAZ, KGZ, TJK, disputed territories	Asia	10322	12	13.30
Thukela	LSO, ZAF	Africa	1975	150	4.36
Vardar	BGR, GRC, MFD, SRB	Europe	2126	303	7.44

consider other important components of international agreements that are considered to improve transboundary cooperation, like the existence of provision for data sharing, the presence of arrangements for public participation and key RBOs' characteristics that increase their effectiveness. Our study also ignores informal relationships between countries regarding water management, meaning that some BCUs and river basins may be better equipped than this analysis shows.

Third, when referring to specific countries in this paper we are not implying that a country is a "monolithic" entity with no diversity and internal tensions over water issues, negating the diversity of opinions held by various subsets within national borders regarding their values and priorities for water management. Since foreign affairs (generally including decisions to engage in cross-border conflict or cooperation) occur at the level of the national government, when describing interactions between countries we are referring to relations between governments, and to opinions and decisions made by who Zeitoun et al. (2016) define "the elite cadre of decision-makers—namely heads of state, negotiators, and high-level members of water bureaucracies".

Fourth, this analysis assumes that institutional capacity will remain fairly static in the near future, despite a global record of institutional growth and evolution. For existing treaties, this seems like a reasonable assumption as they tend to remain stable for decades, and the institutional variables evaluated in this study (presence of a treaty, presence of an allocation mechanism, presence of a flow variability mechanism, presence of a conflict resolution mechanism, presence of a river basin organization) change relatively infrequently. Nonetheless, new treaties are signed at an average rate over three per year since the 1960s (Giordano et al., 2014) and components of treaties may be amended and river basin organizations may be re-organized regularly and frequently. These amendments can contribute to increase the efficiency of transboundary institutions but often bring about changes that are unlikely to be detected in global studies like this one. Moreover, there is no credible way of modelling and projecting at global level how transboundary institutions will evolve, as the trajectory of each institution is unique and influenced by a myriad of factors and conditions.

Fifth, the key factors were identified as possibly exacerbating the risk of transboundary conflict are only a sub-set of the many factors that could potentially impact international hydropolitical relationships. Other important factors that have the potential to disrupt hydropolitical relations include competition among water use sectors or degradation of water quality. Though factors such as these could be researched further in a future arena, they are beyond the extent of this study.

Sixth, some of the values calculated for exacerbating factors within the BCUs have a lower level of confidence. The size of some BCUs caused problems, as models were limited in calculating past and projected water variability (both for the baseline and the projected Coefficient of Variation of annual runoff) and the resolution of GRACE data was too large as compared to the size of some BCUs. Another problem was the lack of data or up-to-date data for some indicators. This is partially due to the nature of some of the factors (interstate armed conflict, water conflict/cooperation, and the risk of internationalization of basins due to armed conflict) that can evolve rapidly enough that current realities may not be accurately reflected. In the case of the factor measuring interactions over water, the selection of the 2000 cut-off date for the "recent" water events was linked to data availability, as the most recent update of the dataset covers the period 2000–2008 (De Stefano et al., 2010). Since combining the pre-2000 and post-2000 datasets presented some methodological challenges, we opted to use the 2000–2008 dataset. The comparison of trends for the periods 1948–1999 and 2000–2008 showed that there are no substantial differences between the two periods, which suggests that using a year prior to 2000 as a cut-off date would have not changed the results of the analysis.

Finally, dam and diversion project data is based on the best information that is publically available, which could exclude additional water infrastructure projects. Another complication of this dataset is that the status of these projects evolve quickly. Some could be further delayed, others could have been cancelled. Our dataset is smaller than that compiled by Zarfl et al. (2015), as that dataset includes dams both inside and outside of transboundary basins and has a lower threshold for capacity (over a 1 MW capacity). Moreover, the Zarfl et al. dataset does not include diversion projects and each dataset draws from different sources of information. The differences between these two datasets underscore the need for a publically available dataset in which states, national donors, and international donors could submit information about new dam and diversion projects.

While noting the constraints of our approach, and recognizing the inherent tension between the use of global indicators and the capacity to be critical about what they represent at the local and regional scales, we also are cognizant that nuanced case studies about conflict and cooperation are best suited to local or basin level analyses using qualitative methods. To our knowledge, only one study has been carried out that attempts to craft global indicators which incorporate

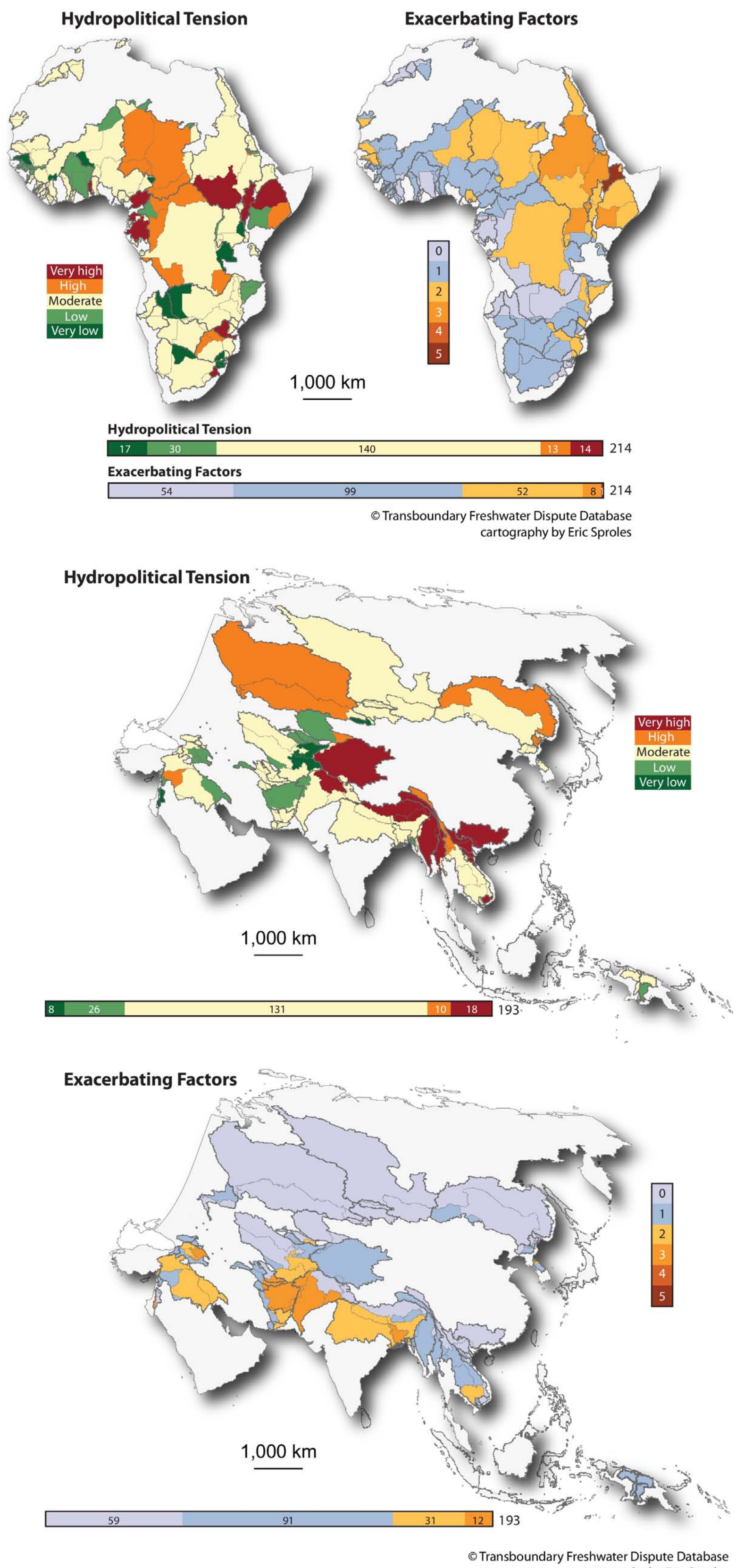

Fig. 5. Hydropolitical tensions and exacerbating factors (changes in terrestrial water storage, projected changes in water variability, per capita gross national income, domestic and international armed conflicts, and recent history of disputes over transboundary waters) by continent.

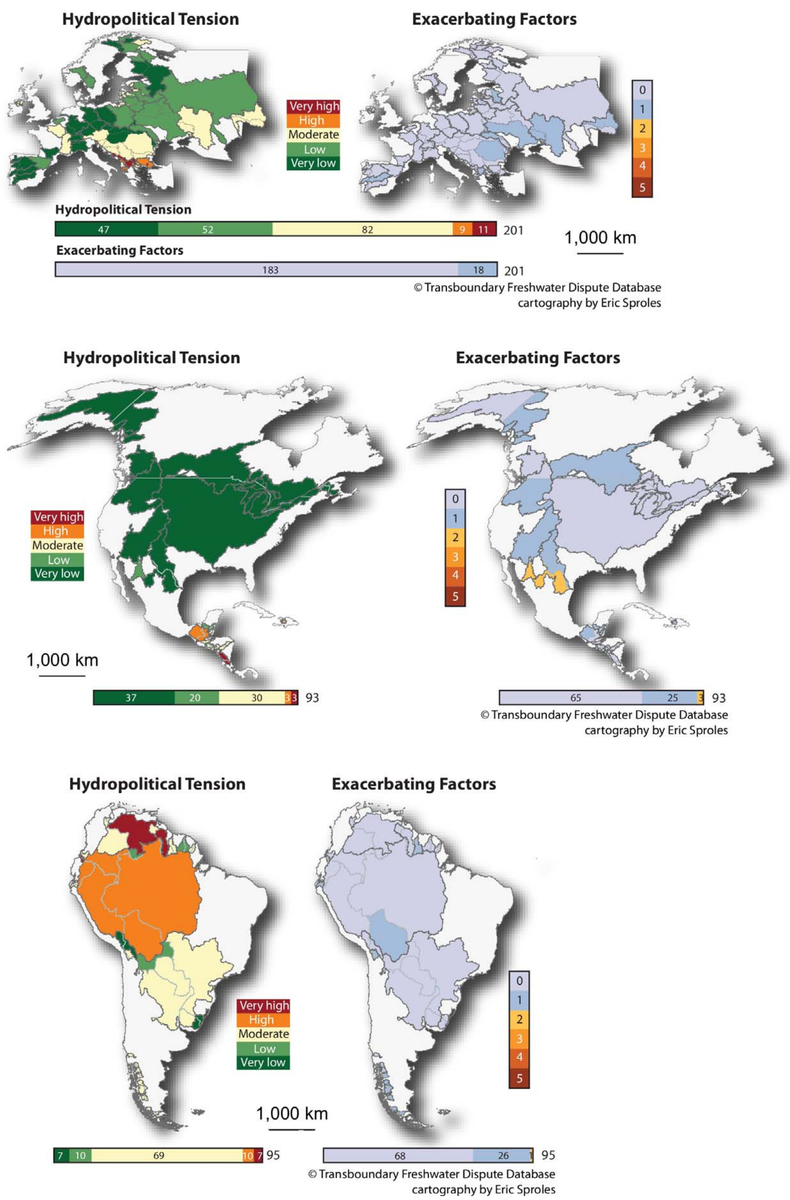

Fig. 5. (*continued*)

Table 6
Comparison of river basin studies identifying basins at risk of future conflict. H = High risk. VH = Very high risk. In bold those river basins that appear in more than one study.

Wolf et al. (2003b)	Bernauer and Böhmelt (2014)	De Stefano et al. (2012)	This study
Aral Sea, **Asi/Orontes**, Ca, Chiloango, **Cross**, **Drin**, Ganges-Brahmaputra-Meghna, **Han**, **Indus**, Irrawaddy, Jordan, Kune, **Kura-Araks**, La Plata, **Lake Chad**, Lempa, Limpopo, Mekong, Nile, **Ob**, Okavango, Red, Saigon, Salween, Senegal, Song Vam Co Dong, **Tigris-Euphrates**, Yalu, Zambezi	**Asi/Orontes,** Atrak, Baraka, Daoura, Buzi, Colorado, **Cross,** Dasht, Dnieper, Dniester, Don, Dra, Elancik, Fenney, Firth, **Gash,** **Grijalva,** Guir, **Han,** Hari/Harirud, Ili/Kunes He, **Indus,** Kaladan, Kogilnik, Lake Natron, Lake Turkana, Medjerda, Mius, **Ob,** Oued Ban Naima, Oueme, Rio Grande (NA), **Sabi,** Samur, Sarata, St. John (NA), Sujfun, Tafna, **Tigris-Euphrates,** Tijuana, **Tumen,** Umba, Volga, Yakui	**Asi/Orontes,** Catatumbo, Chira, Congo/Zaire, **Gash, Kura-Araks,** Lake Chad, Lotagipi Swamp, Neman, Nestos, Niger, Oued Bon Naima, Sarata, Zapaleri	Amazon (H), Artibonite (H), Bei Jiang/His (VH), Benito/Ntem (VH), Ca/Song-Koi (VH), Chiriqui (VH), **Drin** (VH), Essequibo (H), **Grijalva** (H), Bei Jiang/Hsi (VH), Irrawaddy (VH), Isonzo (H), Juba-Shibeli (H), Krka (VH), **Lake Chad** (H), Lake Prespa (H), Lake Turkana (VH), Ma (VH), Mira (VH), Maritsa (H), Mono (VH), Neretva (VH), **Ob** (H), Ogooue (VH), Orinoco (H), Red/Song Hong (VH), **Sabi** (VH), Saigon (VH), Salween (VH), Sanaga (VH), San Juan (VH), Struma (H), Tarim (VH), Thukela (VH), **Tumen** (H), Vijose (H), Vardar (VH)

issues of social justice and structural violence around transboundary water management (Watson, 2015) and, as the study is so recent, we are hopeful that future research will be able to tap into this potentially robust approach. In the meanwhile, we see the value in carrying out research at a global scale in order to suggest red flags for regions that may need to be looked at more closely using the qualitative and critical tools at one's disposal, and we believe that they can help a) identify basins that even from a formal point of view have a limited capacity; and b) spur the discussion about what is actually still missing in those basins where our assessment does not identify major problems while local actors express strong concerns about the quality of transboundary cooperation.

This study paves the way to two potential research lines: one aimed at the improvement of the existing global metrics and another focused at learning from other levels of analysis.

Regarding the first topic of research, future studies could consider issues that were not addressed in this work, including the existence of arrangements for data sharing, the existence of provisions for public participation and of key characteristics that have proven to be crucial to ensure RBOs' effectiveness. Another important gap to be addressed is the assessment of the quality of transboundary cooperation. This is an elusive topic in general and particularly in global studies. In order to measure performance of transboundary institutions, it could be interesting to conduct a global survey among water practitioners in transboundary river basins to evaluate strengths and shortcomings of the current institutional cooperation frameworks. Despite the limitations and subjectivity of such a survey, it would add a new dimension to the analysis, complementing existing datasets that are based on documentary or modelling analyses.

In relation to multilevel cross-learning, global studies receive important inputs from local studies, which are key to identify drivers, factors and circumstances that can assuage or fuel tensions. Indeed, case studies can demonstrate or refute propositions that can subsequently mapped at a global scale. In this context, the systematic comparison of findings obtained across a number of cases can be of great interest to build sound foundations for the identification of factors that have consistently proved to contribute to transboundary cooperation. Other scales of management can also be source of inspiration and lessons for transboundary rivers. For instance, the interactions over water between states belonging to a federal political system can have similarities with interactions between riparian sovereign countries. Over 300 basins in the world are within or are shared by countries having a federal political system (Garrick and De Stefano, 2016) and the study of institutional arrangements to manage inter-state tensions could provide relevant lessons for the international level.

6. Concluding remarks

This indicator-based analysis combines environmental, political, and economic metrics to identify hydropolitical vulnerability and resilience in transboundary watersheds at a global scale. This study contributes to the understanding how the recent proliferation of development in some regions of the world may play a role in global hydropolitical resilience. The development of new dams and diversions is very unevenly distributed. Some basins will be much more impacted than others. The distribution of new water infrastructure is primarily focused in the upper portions of the BCUs and in emerging or developing economies that require increased hydropower and water regulation to sustain their economic development. Many of these areas still lack well-developed instruments for transboundary cooperation. The exacerbating factors may prove to have a greater impact in certain basins. Based on our results, this analysis identifies regions and basins that merit further explicit investigation to truly understand the risks of hydropolitical conflict. The ability to understand when (and where) these variables combine to potentially create conflict is critical to managing and transforming future conflict.

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