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Conflict and cooperation in the water-security nexus: a global comparative analysis of river basins under climate change

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Abstract

Adequate fresh water availability is an important factor for human security in many parts of the world. In transboundary river basins, decreased water supply due to local environmental change and global climate change, and increased water demand due to growing populations and continued economic development can aggravate water scarcity. Contrary to the claim that water scarcity may result in an increased risk of armed conflict, there is no simple relationship between freshwater availability and violent conflict. Other crucial factors need to be taken into consideration that also directly influence resource availability and personal human wellbeing. In this review, we assess the scientific literature on conflict and cooperation in transboundary river systems. Most international river basins are already jointly managed by the riparians but successful management in times of climate change necessitates the inclusion of more factors besides mere allocation schemes. On the basis of a substantial body of literature on the management of transboundary watersheds an analytical framework of the water-security nexus is developed that integrates the physical and socio-economic pathways connecting water availability with conflict or cooperation. This framework is subsequently applied to two transboundary river basins – the Nile River and the Syr Darya/Amu Darya – as they represent two world regions that could become future water hot spots. An improved understanding of the developments leading to water conflicts and their interaction can help to successfully reduce the risk of water conflicts in these regions and to move towards increased cooperation among the riparians of transboundary river systems.

1. Introduction

Water is of fundamental importance for life on our planet and a prerequisite for human development. The daily availability of drinking water is an essential human need and adequate sanitation is vital for human health and human security. Water is also an important economic factor as it is essential for agriculture, forestry, and fishing (Oki and Kanae 2006). Rivers are an important natural transport mechanism for fresh water, often connecting regions of high rainfall with drier areas. Rivers provide drinking water for the population, allow

the development of agriculture, and also serve the transportation of goods and people. Throughout history until today, rivers thus have had a special importance for human settlements and activities.

In recent decades, the environmental and social boundary conditions of water use have changed considerably, making water a scarce resource in certain regions of the world and river basins even more essential sources of freshwater. Not only has the world's population increased drastically but also the industrial and agricultural use of the world's water resources has intensified considerably, causing the amount of water available to each individual to diminish over time. This trend is thought to be augmented by climate change, which is likely to lead to altered precipitation patterns and higher evaporation rates, thus affecting the overall water availability in river systems (Field and Van Aalst 2014, Stocker et al. 2014).

The problems associated with the utilization of water from river systems become more pronounced if a river system is shared by several riparian countries. If a country covers its water supply by using fresh water inflows from outside its own territory there is a dependence on upstream riparians. An alternative form of water interdependence is a river that is shared between two or more states along a border between them. There are 263 transboundary river systems in the world, which are vital sources of water for 40 per cent of the global population (Wolf 1998). Riparians have to agree on how the amount of water available in the watershed is divided, which is especially problematic if a river system is shared by countries with significantly divergent interests and a history of conflict and distrust.

Unilateral use of the limited water resources may become a trigger of disputes and conflicts (Fischhendler et al. 2011, Bernauer and Siegfried 2012). An environmental conflict perspective assumes an increasing conflict potential with water stress and is often based on theoretical frameworks that suggest that resource scarcity is associated with negative social effects (Wolf 1999). Although there have been numerous cases of disputes and tensions over the division of water from rivers in the past, violent conflict about water resources are by no means a necessary consequence of water scarcity or interdependence. The last interstate war over water dates back many millennia (Wolf 1998) and interstate wars over water are frequently considered to be politically and economically unsound (Brochmann and Gleditsch 2012). In current interstate interactions in transboundary river systems water is only one issue embedded in a multitude of issues affecting conflict or cooperation. Rather than competing with other riparians, a cooperative utilization of water may provide benefits to all countries involved and could trigger further cooperation (Conca 2002).

This assessment examines how physical and socio-economic variables, including political and cultural drivers, interact to affect the likelihood and intensity of water conflict and water cooperation in transboundary river basins. Drawing on related strands of literature that are not sufficiently integrated, we develop an integrated conceptual framework to assess water conflict/cooperation that is subsequently applied in two regional case studies. This review starts with the dominant approach of empirically testing the statistical relationship between water stress and conflict/cooperation in transboundary river basins, including the most widely used definitions and data, and addresses some limitations (section 2). We discuss the relevance of climate change (section 3) and regional perspectives on transboundary water allocation in Africa and the Middle East, and in Central and South Asia (section 4). Based on the integrative conceptual framework of the water-security-conflict nexus (section 5), we explore major pathways between water availability and conflict/cooperation in two exemplary regions (section 6). The key results of the assessment are discussed in the conclusion (section 7).

2. Empirical results on transboundary water conflict and cooperation

Empirical research in this field is growing but still at the formative stage. Much of the already existing literature on conflict or cooperation about transboundary water resources is based on statistical large-N studies. In contrast, other research that focuses on individual case studies or on simulation modeling is less frequent. However, these kinds of studies add different perspectives to the research on water conflict and provide insights that can very well complement the results of the predominant large-N-studies.

Definitions and data

Most quantitative large-N-studies employ very basic measures of water scarcity as the independent variable, which do not represent the temporal and spatial variability of water sources. Most basic is the Falkenmark-Index, which measures the existing renewable quantity of freshwater in relation to the population size (Falkenmark et al. 1989). With more than 1,700 m^3 per person per year of renewable freshwater, a country has a sufficient water supply. Water stress is defined as annual water consumption of 1000-1700 m^3 per capita, water scarcity below 1,000 m^3, and less than 500 m^3 implies absolute water scarcity. Regarding precipitation as a source of water supply, two indicators of meteorological water stress used in the quantitative literature are the Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Index (SPI) that focus on deviations of rainfall from current and historic averages in an area during a specified period and account for excesses or deficiencies in the water balance (O'Loughlin et al. 2012, Theisen et al. 2012). Most studies fail to distinguish between progressive (long-term) or acute (shocks) scarcity, often using measures of scarcity that either have a low temporal resolution or are static (Meierding 2013). Nonetheless, these static measures do have their merits as they provide initial information on the physical setting of a region with regard to water availability. Changes in this physical background usually occur on a longer timescale than changes in socio-economic factors affecting water use. Of course, dynamics in water availability also have to be taken into account for in-depth assessments of particular regions or river systems.

With regard to conflict as the dependent variable, many definitions take a broader view by emphasizing the outcomes of conflict. E.g., conflict is conceived as *"…the result of two or more parties (individuals or groups) having or perceiving to have incompatible goals and interests and acting upon these differences"* (Hammill et al. 2009). This includes contention over both tangible resources (e.g. water, land), and intangible resources (e.g. claims to power or status), and does not necessarily require the use of violence as a means of conflict. However, many studies focus on violent forms of conflict such as armed conflicts (Gleditsch et al. 2002) or militarized interstate disputes (Ghosn et al. 2004) since it is more difficult to create good datasets on non-violent conflict events. Violent conflicts usually receive more attention from the news media, NGOs or scientific experts, which are the main sources for the respective databases. It is also harder to define the existence/beginning of a conflict or conflict event if no clear-cut quantitative threshold is available such as the number of fatalities (Day et al. 2015). Nonetheless, Böhmelt and others (2014) have collected data on the apparently continuous dimension of cooperative or conflictive events over water.

The Basin-At-Risk (BAR) event scale and dataset is also a notable exception in this context and distinguishes between seven types of water conflict, ranging from verbally expressed discord to war (Wolf et al. 2003). The most comprehensive dataset on water conflicts is the Water Conflict Chronology, which collected 265 entries of water conflicts from 3000 BC to 2014 AD. The chronology indicates a rising trend of mainly subnational conflicts over water, away from international disputes (Gleick 2014).

In general terms, cooperation is in place between two or more parties when they agree to take mutually beneficial action that would not occur without such agreement. In the water context, cooperation includes "*both formal agreements (such as river treaties) and non-*

institutionalised forms of cooperation such as meetings between environmental ministers to initiate or foster joint management of shared basins" (Kalbhenn et al. 2012). According to the BAR scale of conflict and cooperation, water cooperation can range from minor official exchanges to the voluntary unification into a state/nation. Quantitative research has most often used the existence of a (transboundary) river treaty, agreement, or institution as an indicator of water cooperation (Bernauer and Siegfried 2012). The most prominent dataset covering transboundary water-related conflict and cooperation is the Transboundary Freshwater Dispute Database (TFDD) (Wolf 1999). A slightly different methodology is employed in the International Water Cooperation and Conflict (IRCC) database (Kalbhenn and Bernauer 2012), which results in a larger number of recorded events than in TFDD over the same time period.

However, it is important to note that strict conflict-cooperation distinctions can be misleading, especially if conflict is framed in negative terms while cooperation is judged as positive per se. Firstly, conflict can be an important catalyst of progressive social change such as democratization or a more fair and sustainable use of water resources (Mouffe 2005), while cooperation can obscure severe water-related inequalities or forms of political domination (Cascão 2008). Secondly, forms of conflict and cooperation can exist in parallel. In such cases, cooperative actions can mask or even accelerate existing water conflicts and vice versa.

Review of statistical studies

While the literature is expanding, there is little consensus yet on the impact of water scarcity on social interactions, and significant deficits remain in the understanding of fundamental issues. In a comprehensive review, Johnson and others (2011) selected 47 relevant studies investigating the relationship between fresh water scarcity and either conflictive or collaborative interactions. Of 19 studies exploring interstate interactions, one was related to freshwater scarcity while the remaining 18 were specifically related to transboundary river basins. Five of these studies investigated violent conflict and three focused on non-violent conflict, i.e. river claims between dyads.

In this paper we give the reader a comprehensive overview of the current state of research and provide an up-to-date review of statistical studies on conflict and cooperation around transboundary river basins. Extending previous work, we conduct a systematic assessment and open the debate for the subsequent presentation of an integrative conceptual framework of the water-security-conflict nexus, which is exemplarily applied to the cases of the Nile River Basin and the Syr Darya and Amu Darya river systems.

Cross-case studies exploring historical trends in transboundary water conflicts find that conflictive interactions are rare (Wolf 1998, Yoffe et al. 2003, de Stefano et al. 2010). Since 1948, supposedly 37 violent conflicts occurred, in which water played a major role. 30 of these conflicts alone were fought between Israel and its neighbors. On the other hand, there were 1831 "water-related incidents" in the past fifty years in TFDD, of which more than two thirds were of a cooperative nature (Wolf et al. 2003). The IRCC database even lists 4797 events in the same time period but also concludes that most of the recorded events are cooperative (Kalbhenn and Bernauer 2012). De Stefano and others (2010) find that between 1948 and 1999 and from 2000 until 2008 there have been moves towards less cooperative interactions between some countries. But most negative events were rather moderate expressions of discord and hostility with little evidence of violent conflict.

Table 1 summarizes the large-N literature on water and transboundary conflict. Similarly to the assessment of Johnson and others (2011), we found strong dissent in this literature. Few studies investigate the links between reduced precipitation or hydropower development and violent intrastate conflict, and the results are quite ambiguous. By contrast, there is agreement among the four studies conducted that low water availability increases the risk for

interstate disputes, especially between neighboring states. However, when exploring the relationship between adjacent countries with shared rivers, only five studies claim that a shared river increases the risk for violent conflicts between states, while twelve studies find no support for such a link. Furthermore, robust treaties and institutions can mitigate water-related conflict and facilitate cooperation even under hydrological stress (Hensel and Brochmann 2007, Tir and Stinnett 2012, Dinar et al. 2015).

Variable	significantly increases the risk of violent conflict between states	does not significantly increase the risk of violent conflict between states
shared rivers	(Furlong et al. 2006) (Gleditsch et al. 2006) (Kirby et al. 2010) (Phillips 2012) (Toset et al. 2000)	(Algamal 2011) (Bernauer and Siegfried 2012) (Bhaduri et al. 2011) (Brochmann and Gleditsch 2006) (Brochmann and Gleditsch 2012) (Deng et al. 2012) (de Stefano et al. 2010) (Dinar and Wolf 1994) (Drake 1997) (Onishi 2007) (Wolf 1998) (Yoffe et al. 2003)
reduced precipitation	(Devlin and Hendrix 2014)	(Devlin and Hendrix 2014)
low water availability	(Furlong et al. 2006) (Hensel et al. 2006) (Siegfried et al. 2012) (Tir and Stinnett 2012)	(Dinar et al. 2011)
hydropower development	(Rahaman 2012)	(Pearse-Smith 2012)

Table 1: Overview of findings of research on the water-conflict link in transboundary river basins.

Despite evidence that water-related interactions are more often cooperative than conflictive, there has been a strong bias in water research on conflictive events. However, there are studies that find that signing of a water treaty positively influences future cooperation between the treaty partners (e.g. Brochmann 2012), that water scarcity has a significant and positive relationship with the existence of river treaties (Tir and Ackerman 2009), and that water scarcity enhances the incentives for riparians to cooperate (Dinar et al. 2011). When considering non-linear relationships, certain studies found a curvilinear relationship between the likelihood of cooperation and water scarcity (Dinar et al. 2007, Dinar and Albiac 2009, Dinar et al. 2010). This suggests that transboundary water cooperation is most likely if water is neither extraordinarily scarce nor abundant. The projected amplification of hydro-climates (Fung et al. 2011) thus has the potential to reduce international water cooperation.

In sum, research largely indicates that there is little evidence that shared rivers per se increase the risk of violent conflict between riparians. Water scarcity, by contrast, seems to make violent interactions between states, including those sharing river basins, more likely. But this effect can be mitigated via well-designed institutions (Brochmann and Hensel 2011).More importantly, water scarcity is empirically more likely to produce treaties and other forms of cooperation, while water-related interactions in general are more often cooperative than conflictive. There is no convergence on the conditions and pathways leading to either conflict or cooperation.

Addressing the limitations of statistical studies

Without major progress in this field, it would be difficult to move from ex-post empirical analysis to predictions and forecasts (Bernauer and Böhmelt 2014), in particular in the context of climate change. While data on armed conflict are globally available, there is a lack of adequate and comprehensive data across other levels of the BAR scale, and many studies rely on simple binary measures of conflict and cooperation (Johnson et al. 2011). Data at the subnational level are at times unreliable, especially for peripheral regions (Ide and Scheffran 2014), and the results of large-N analysis are dependent on the statistical model used (Selby 2014). There are also limitations with regard to the measurement of non-violent conflict or collaborative actions, e.g. because such events attract less media attention and are likely to be underreported in official statistics (Day et al. 2015). Consequently, researchers trying to investigate non-violent and cooperative forms of water interaction with a large-N methodology face several problems. This may explain the dominant focus on water conflict rather than on water cooperation in this field of research. The links between intra-state and international conflict or cooperation are far from being well understood as well, and international interactions about river basins are hardly considered as two-level games (Putnam 1988). Similarly, there is need for more research into the intermediate factors between water availability and conflict/cooperation, including food prices, economic loss, symbolic disputes, public grievances, or elite manipulations (Meierding 2013, Ide 2015).

Furthermore, it is unclear how the currently dominant large-N studies can take into account important variables such as social constructions, perceptions and interpretations of water problems (Norman et al. 2012). The same holds for persisting inequalities, political domination, and hidden conflicts, which are masked as cooperation (Selby 2003). Well-conducted case studies have a significant potential to produce innovative findings on these issues and are also able to provide considerable explanatory power (Zeitoun and Warner 2006). Case studies could also regard transboundary interactions on river basins as multi-level and multi-agent games that are not only shaped by international factors but also by domestic politics, discourses, capacities, and power relations (Canter and Ndegwa 2002, Feitelson 2002). Such research could be inspired by a conceptual framework integrating the complex causal mechanisms and relationships between hydro-climatology, water flows, socio-economic conditions, culture, and institutional capacities on global and regional scales. In section 5, we suggest such a framework.

3. Climate change, water security and conflict

Climate change coupled with rapid economic development in many regions of the world will affect the dynamics between water demand and supply patterns as well as water quality (Schellnhuber et al. 2013). Adding to an already complex situation (de Stefano et al. 2012), global warming may not only influence the physical water supply in a given river system but also affect factors governing water demand such as the amount of water needed for drinking and irrigation purposes (Tir and Stinnett 2012). An increased average temperature generally leads to greater evaporation, which together with diminishing rainfall leads to soil degradation and declining river flows as well as reduced percolation into aquifers. Progressing climate change is expected to increase the frequency and amplitude of extreme weather events such as droughts and floods over the next century, which increases related risks and affects the capacity to adapt or cope with these changes (Field and Van Aalst 2014). When drier areas become even drier and moist areas even wetter the water balance deteriorates, possibly leading to regional scarcity or abundance of water resources (Fung et al. 2011). More intense and more irregular precipitation in short periods of time may lead to flooding, soil erosion, and large fluctuations in water levels of rivers. Many river systems are facing major challenges due to the melting of continental glaciers, which affects the water balance between summer and winter months and leads to increasing flows in the near future and to declining flows in the long run (Field and Van Aalst 2014). Regions that experience recurrent

water stress and are simultaneously sensitive to climate change include the Sahel, South Africa, the central U.S., Australia, India, Pakistan, and North East China (Hanasaki et al. 2008).

The fact that the impacts of climate change will be spatially heterogeneous makes a clear distinction from the impacts of socio-economic factors difficult. Current disputes about the allocation of freshwater among countries are possibly aggravated by the impacts of climate change in the coming decades. The implications of climate change for interstate relations in transboundary river basins eventually depend on the link between water scarcity, conflict, and cooperation. Based on section 2, we cannot deny that climate change may increase the intensity or frequency of international river disputes. However, cooperation in the face of hydrological changes in river basins is still the more likely option, particularly if adequate institutional mechanisms exist (Brochmann and Hensel 2011, Tir and Stinnett 2012, Mianabadi et al. 2015). Various approaches are suggested for “climate-proof” water treaties including adjustable allocation strategies and water-quality standards, response strategies for extreme events, amendment and review procedures, and joint management institutions (Cooley and Gleick 2011). In general, climate change is considered to have a greater influence on patterns of peace and conflict within states (Gleditsch 2012), and the link between climate change and intrastate conflict is complex and heavily disputed (Scheffran et al. 2012, Buhaug 2015).

Considering the complex water-security nexus, debates about climate change may fuel concerns about future water scarcity, thus facilitating a securitization and militarization of transboundary water resources and eventually self-fulfilling prophecies of future water conflicts (Feitelson et al. 2012, McDonald 2013). But in line with the environmental peace perspective, policy makers can also conceive climate change (independent of its “real” hydro-meteorological impacts) as a common threat that could facilitate collaborative mitigation and adaptation measures as well as trust, mutual understanding, and eventually reconciliation (Amster 2013, Ide and Scheffran 2014).

4. Regional water conflict and cooperation in transboundary river basins

More than a quarter of the world‘s population lives in water-stressed areas according to Oki and Kanae (2006) and more than one billion people have no access to safe and clean drinking water (Watkins 2006), a number that is expected to substantially increase in the coming decades. Growing population densities and economic activities, particularly in urban areas, and changing patterns of water use are challenging the limited water resources that are available to humans (Arnell 2006). The effects of environmental and social change on the net water availability are quite diverse depending on the geographic region and the size of the river basin. In the following, we will provide a condensed review of water-conflict linkages in selected regional hotspots where climate change interferes with local environmental and socio-economic factors that affect conflict and cooperation (Kirby et al. 2010).

Fig. 1 gives an overview of the world’s transboundary river systems and indicates the regions that experience physical water stress, which is particularly high in Central and South Asia, around the Mediterranean, and in parts of Northern America. It has to be noted that this physical setting is only one factor affecting the possibilities for conflict and cooperation. Also, whether a given amount of water available at a particular location is sufficient to support the population not only depends on the physical but also on the societal pressures on water resources, including conflict. Therefore, identifying areas that are exposed to either or both pressures – whatever the link between them may be – provides useful baseline information for the subsequent analyses. More detailed assessments of Africa and the Middle East and Central and South Asia area given below. These are not necessarily the areas with the highest physical water stress per se but represent areas, in which there are considerable interactions between the riparians of transboundary river systems. Consequently, these

regions are particularly relevant with regard to interstate interactions that may be conflictive or cooperative or maybe even both simultaneously. The case study on Africa and the Middle East encompasses fundamentally different regions that have diametrically different dependencies on river water. Incidentally, the dependency on river water for livelihoods is less relevant in regions with low water stress in Sub-Saharan Africa.

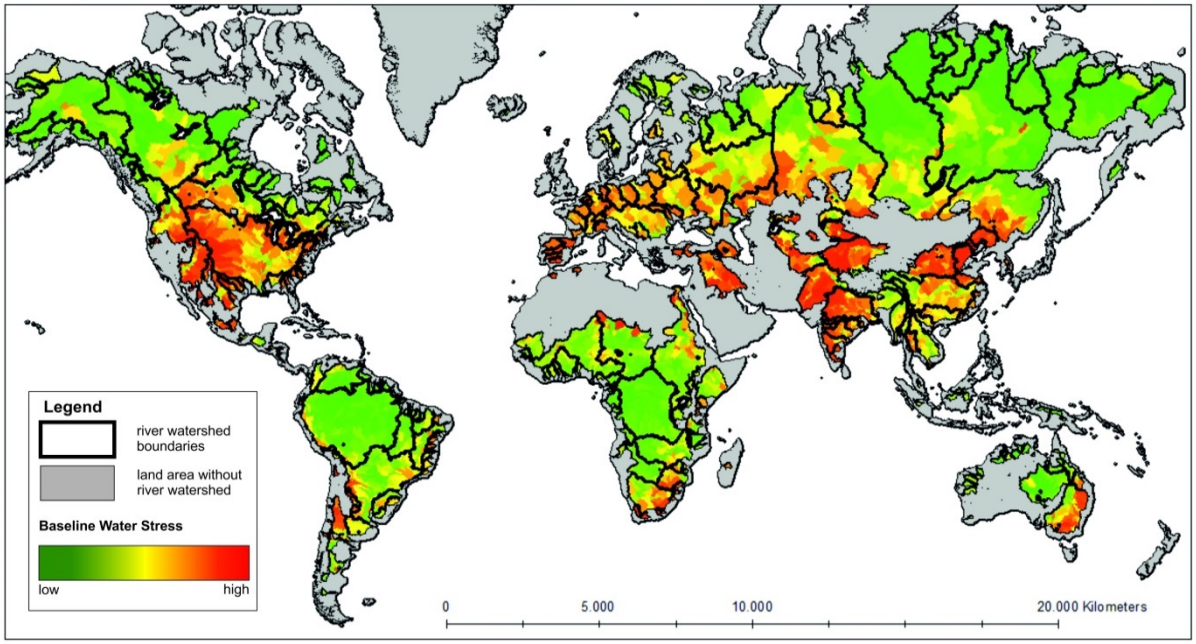

Figure 1: Baseline water stress in the world's transboundary river systems (based on data from Gassert et al. 2013). Baseline water stress is a measure relating total water withdrawal in a given area to total available blue water.

Two additional maps are presented for each region (Figs. 2 and 3), illustrating indicators of physical water scarcity and violent conflict as one indicator of societal pressure (based on the ACLED and PRIO/UCDP databases). The maps rather visualize which of the regions are affected by either, none or both of these two pressures and is not supposed to suggest a causal relationship between them. Note that the choice of the two case study areas is based on the fact that the applicability of the framework presented in this paper can be readily shown and not to suggest that these regions are particularly violent with regard to water resources.

Africa and the Middle East

North Africa

Large transboundary river systems shape the African continent, the most prominent being the Nile, the Congo, the Zambezi, the Senegal, the Niger, and the Orange River. In many countries, particularly in North Africa, major parts of the populations rely on water from rivers for their daily sustenance. In general, the water availability in the large transboundary river systems of the continent is adequate as the physical baseline water stress is relatively low in most parts (Fig. 2). Areas with high water stress adjacent to large rivers are only found in the downstream areas of the Nile River Basin and in South Africa. Therefore, the dependence on river water for livelihoods is more important in these areas and resembles that of the Middle East rather than that of Sub-Saharan Africa. To study the role of conflict, several conflict databases offering geo-referenced information on armed conflicts in Africa have been compiled and related to water stress in Africa.

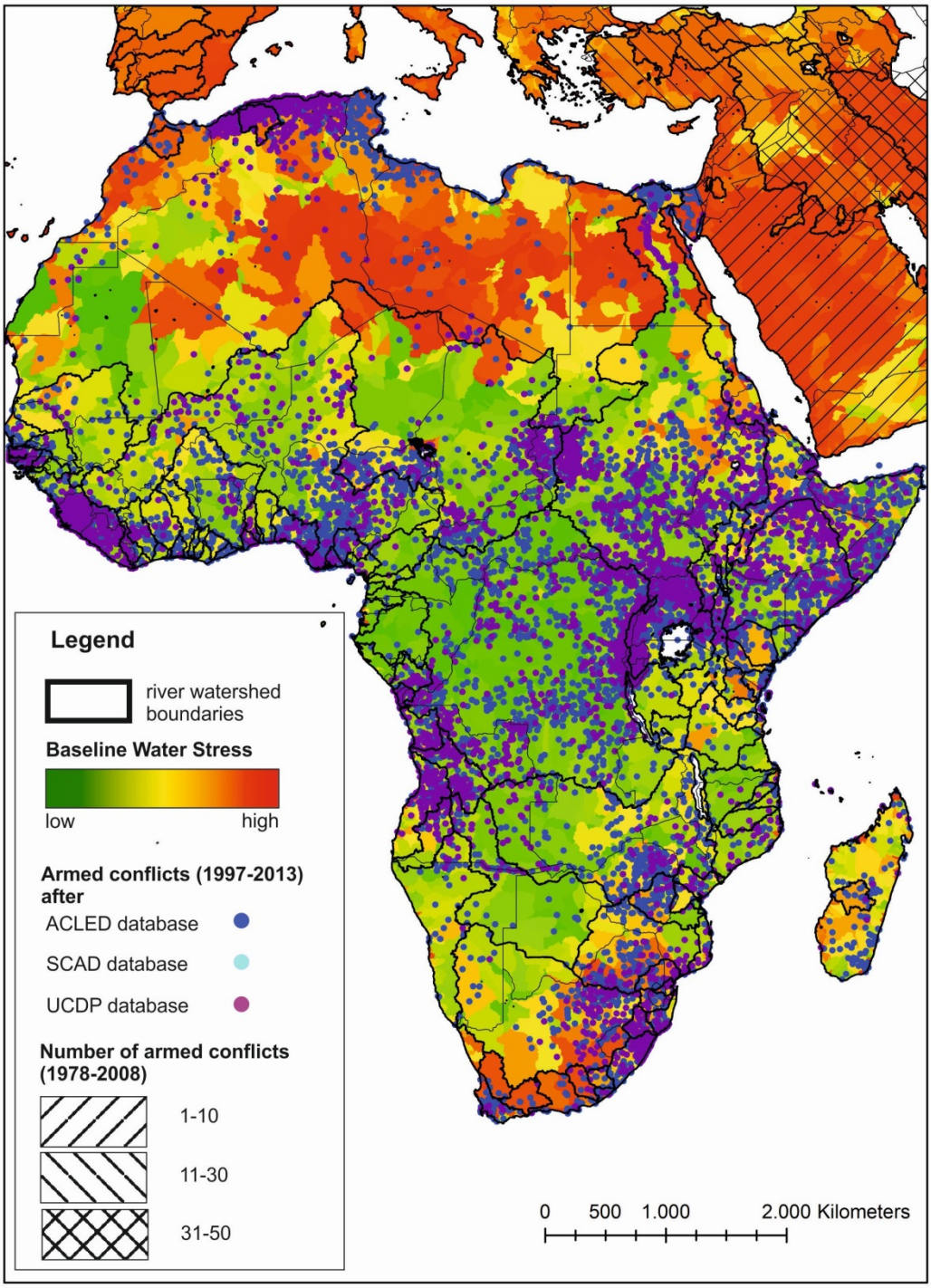

Figure 2: Illustration of baseline water stress in river basins and armed conflict events since 1978 in Africa and the Middle East (Gleditsch et al. 2002, Raleigh et al. 2010, Salehyan et al. 2012, Gassert et al. 2013), indicating areas that are affected by water stress and/or conflict stress. Georeferenced conflict events in Africa are shown in dots; country-based armed conflicts in the Middle East are represented by shadings (technical assistance by Leonard Borchert). Note that the simultaneous occurrence of water stress and conflict in the same location does not imply a causal relationship between the two phenomena.

Conflicts are most numerous in areas with particularly high population densities that in many cases coincide rather well with the streams of the large rivers (Fig. 2). This points to a spatial correlation but does not constitute a causal relationship. The reasons for this development are manifold and include global drivers such as population growth, neoliberal economic

development, and climate change. All these combined have an effect on the possible occurrence of conflict or cooperation. Consequently, conflict hot spots often do not coincide with areas of particularly high water stress.

Sub-Saharan Africa

Besides the Nile River (which is analyzed as an exemplary case in section 6), there are several other important transboundary river basins in Africa that are also jointly managed by the riparians. Particularly in Western Africa there are successful water sharing schemes (Bhaduri et al. 2011), e.g. in the Volta River Basin where transboundary water flows are linked to hydropower exports in the allocation agreement. The same holds for the Okavango River Basin where water allocation schemes can be used to avoid or mediate conflicts between the riparians (Hamandawana et al. 2007). This supports the notion that water management schemes in Africa should not only focus on specific water amounts but should be more comprehensive by also addressing issues of equity, sustainability, and maximum efficiency (Ashton 2002). On this basis, well-structured agreements can foster cooperation through water interdependency.

The Middle East

For various reasons, the Middle East has been frequently cited as a potential arena of "water wars" (Amery 2002). Parts of this region are characterized by an arid or semi-arid climate, an imbalance between water demand and supply, as well as already tense interstate relations (Shuval and Dweik 2007). The region is also characterized by several transboundary rivers and a high symbolic relevance is often attributed to water (de Châtel 2007). Water interaction between Israel and Palestine regarding the Jordan River and transboundary aquifers has been intensively studied (e.g. Selby 2003, Feitelson et al. 2012). Severe water-related inequalities (Selby 2013) and conflictive dominant discourses (Fröhlich 2012) are the main drivers of the Israeli-Palestinian water conflict, which can be observed in parallel to patterns of water cooperation established by the 1995 interim agreement (Zeitoun 2008). Disputes about the Jordan River also exist between Israel and Lebanon and between Israel and Syria (Zeitoun et al. 2013), while patterns of water interaction between Israel and Jordan are largely cooperative, although tensions continue to occur (Jägerskog 2007). Increased water availability due to Israeli desalination and wastewater recycling has the potential to lessen international tensions about water resources. However, no significant de-securitization has occurred yet (Aviram et al. 2014). Conflicts about the Euphrates and Tigris Rivers exist between Turkey as the upstream riparian and Syria and Iraq as the downstream riparians (Harris and Alatout 2010). This conflict could possibly worsen in the future as Turkey continues developing its dam projects (Daoudy 2009).

Central and South Asia

The river basins in Central and Southern Asia are all highly dependent on the supply of water from the mountain ranges of the Himalaya (Fig. 3). Nonetheless, the resulting pattern of baseline water stress in this part of the world is quite heterogeneous: there is substantial water availability in the countries directly adjacent to the Himalayan Mountains whereas water scarcity quickly increases with growing distance.

In Central Asia, the water allocation issues in the Syr Darya and Amu Darya basins have become an important driver for tensions after the demise of the former Soviet Union as these rivers suddenly crossed the international borders of five independent countries. Climate change poses a particular challenge to the region as it tends to aggravate existing water problems and tensions (see the exemplary case study Syr Darya and Amu Darya in section 6).

In South Asia, the economies and livelihoods of approximately one tenth of the world's population depend on the water of the Ganges-Brahmaputra-Meghna River Basin (Rasul 2014). With this considerable demand, effective water management can only be achieved if the focus is expanded from merely the engineering perspective to encompass ecological aspects and hydro-diplomacy as well (Bandyopadhyay and Ghosh 2009), particularly if changing climatic conditions in this region are considered. Such scheme depends on cooperation between the riparians, particularly if areas are closely interlinked like the upstream and downstream areas of the Ganges-Brahmaputra-Meghna River. While studies stress the importance of cooperation among the riparians, there are actually very few reports that such cooperation has been realized (Sud et al. 2015). Nonetheless, there are water treaties in effect in this river basin such as the Ganges River Treaty, which was signed in 1996 for 30 years (Pandey 2014) and became a successful basis for cooperation on water between India and Bangladesh in the past decade. Efforts are now undertaken to include the other riparians of the basin in a broader cooperation scheme.

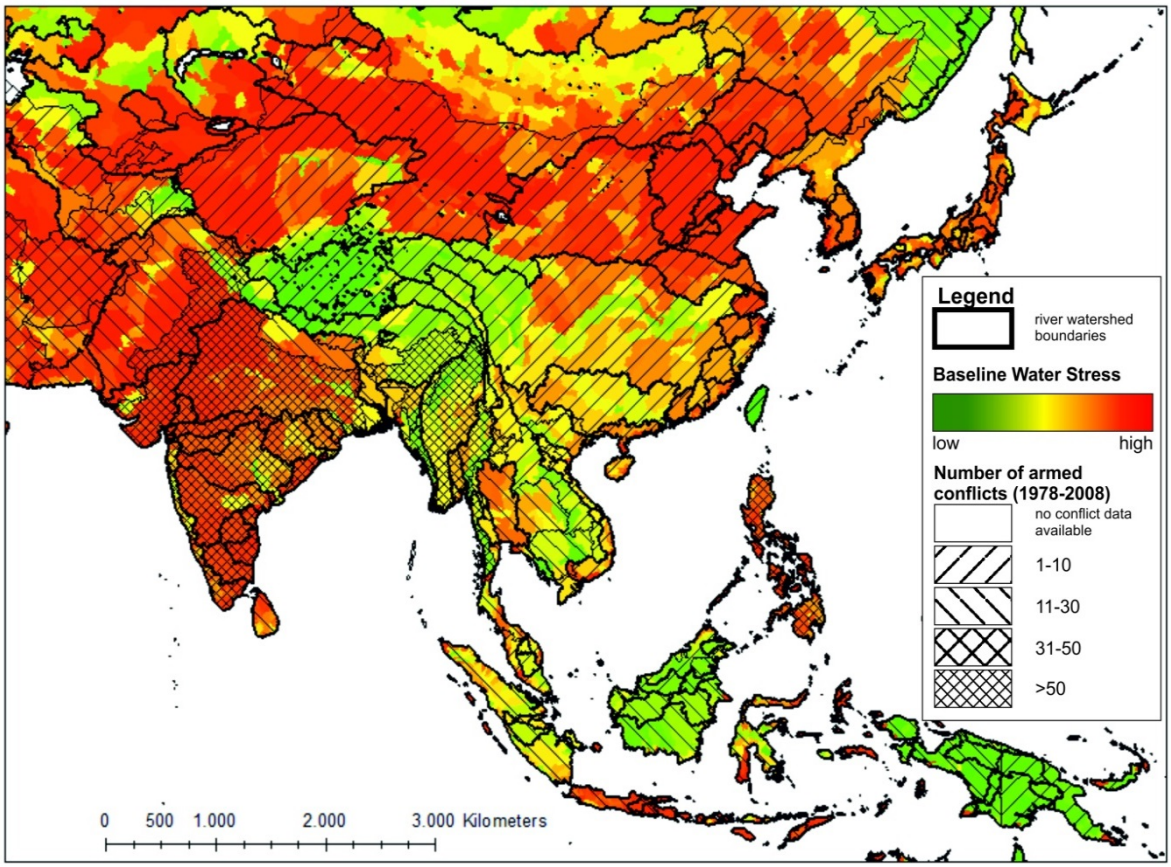

Figure 3: Illustration of baseline water stress in river basins and country-based armed conflicts since 1978 in Central, South and Southeast Asia (PRIO 2011, Gassert et al. 2013). Note that the simultaneous occurrence of water stress and conflict in the same location does not imply a causal relationship between the two phenomena.

Lessons learned

The case study literature confirms the general impression from the large-N studies that water scarcity can be a driver of interstate conflicts in transboundary river systems. However, these conflicts are rather nonviolent in terms of direct, physical violence. Also, cooperative interactions occur more frequently. Nonetheless, cases such as the Jordan River, the Nile River, or the Syr Darya/Amu Darya river system also illustrate that some of the cooperative events are rather superficial and occur in the context of distrust, structural inequalities, and

ongoing conflict (Zeitoun and Mirumachi 2008, Deng et al. 2012). This highlights the point that simple binary measures tend to miss the complexity of certain situations and that water conflict and cooperation should not be conceived as clear opposites. Also, several case studies emphasize the importance of the symbolic dimensions of conflicts over transboundary rivers while statistical analyses can hardly account for such factors. In the next section, we present an integrative conceptual framework that aims to bridge these gaps.

5. Conceptual framework of the water-security-conflict nexus

To assess the complexity of the water-security nexus, we develop a conceptual framework to explore essential linkages and potential pathways between the physical and socio-economic dimensions of water availability and the institutional and political dimensions of water use, which may affect conflict and cooperation across multiple scales. This integrative framework assumes linkages between social and environmental change, its impact on water demand, supply and availability, linkages between water stress and (in)security, responses and interactions between key actors (individuals, communities, states), as well as the institutional setting of water management and conflict resolution. The chain of key pathways and effects can be represented by a scheme with three main compartments that relate to each other by causal linkages and feedback loops (Fig. 4).

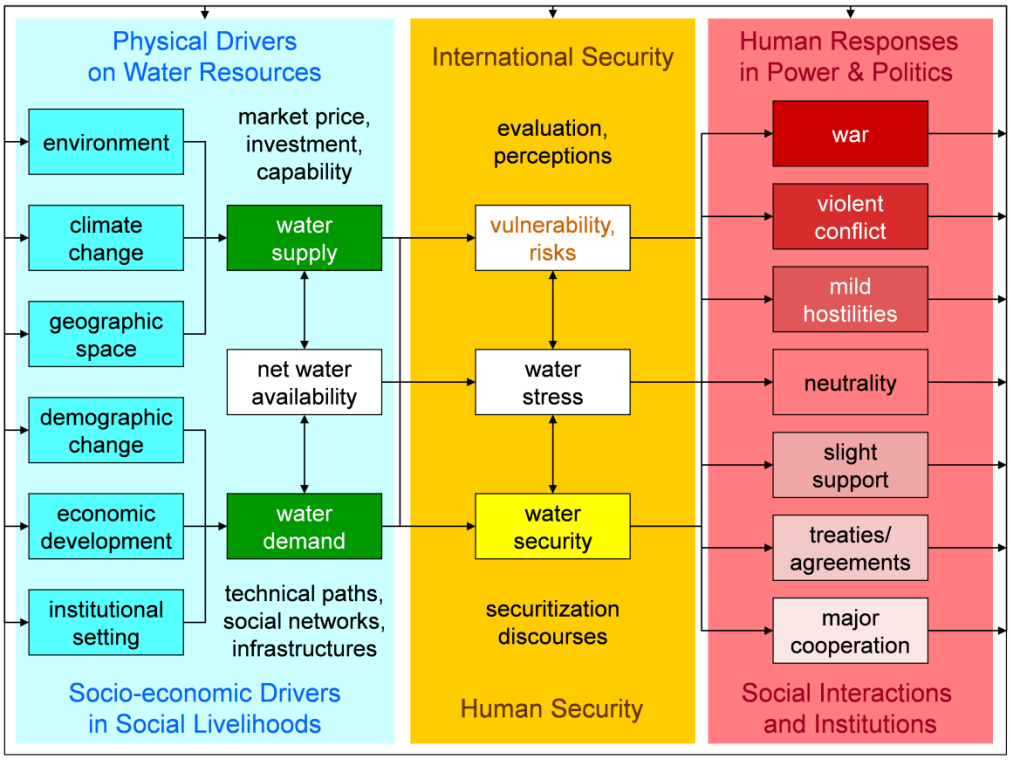

Figure 4: Integrative conceptual framework of the water-security-conflict nexus.

Systemic drivers and pathways of water availability

In the first compartment, the supply of water in a given area is affected by physical dimensions and drivers, which are strongly dependent on the meteorological and geographical characteristics. These include precipitation patterns, evaporation rates, the existence of rivers and underground aquifers, soil characteristics (which influence groundwater recharge), or access to the sea (for desalination). All these are affected by climate and environmental change. Socio-economic structures and dynamics have an impact

on the supply of and demand for water and on economic variables such as water-related investments and the market price of water, economic development and demographic change, the influence of extra-basin actors, forces, and factors, as well as water-related infrastructure and institutional settings.

The balance of water demand and supply is shaped by relevant trends in social livelihoods and networks. These include population growth and the development of human needs, which determine total annual water withdrawal by all economic sectors in a given geographic location relative to the total annually available water flow (Gassert et al. 2013). There is a wide range of potential technical (e.g. dams, irrigation channels, and other engineering measures) and economic pathways (e.g. water pricing, availability and affordability of innovation, water subsidies for agriculture, international food prices, human-induced soil degradation or water management priorities) that have an effect on the overall water availability and determine the degree to which a given riparian experiences water stress.

Evaluation of water stress and water security

Whether water availability is seen as abundant or as scarce is subject to human values. The availability of water is perceived differently by various actors and often a source of heated political disputes (Harris and Alatout 2010). Water also has symbolic dimensions. It is deeply connected to political and religious ideas such as purity (in case of the Ganges), national development (in case of the Mekong), or state building (in case of the Jordan) (Hansson 2001, Jacobs 2002, Fröhlich 2012). Insufficient water availability that is perceived as real can lead to severe value losses and risks that affect water security for vulnerable communities.

Whether increasing water stress and dissatisfaction raise security concerns depends on the associated value perceptions, vulnerabilities, and security conceptions of the respective agents. The security dimensions in the second compartment range from human security concerns to national or international security threats (Zeitoun 2011). Water stress and insecurity are potential drivers of human decisions and discourses, in which different evaluation dimensions and attitudes of stakeholders meet to adjust to and improve the situation by bridging the gap between demand and supply and diminishing dissatisfaction. Besides the utilization of water resources, their control can be disputed, especially when the symbolic value of water is considered high (Selby 2003). The literature of the water securitization discourse is full of examples in which the available quantities of water, promising water development projects, and/or the causes of water problems are heavily disputed between and among scientists, engineers, politicians, and local people (e.g. Mehta 2005, Waintraub 2009, Murtinho et al. 2013).

Human responses and social interactions between conflict and cooperation

In the third compartment individual and collective human responses are addressed as well as the social interactions they induce, possibly turning to conflict or to cooperation. Real or perceived water scarcity (or insufficient control over water resources) in combination with increasing levels of insecurity and securitization can establish an environment of anger, fear, or hostility, creating incentives to engage in conflict and eventually deploy violent means (Stetter et al. 2011, Fröhlich 2012), potentially leading to a self-enforcing cycle of violence. Whether conflicts related to water stress escalate or are contained may not only depend on motivational factors but also on the capabilities and opportunities to act, including the capability to fight and use force. However, there are several examples of water disputes which escalated into violence although one party was considerably weaker and perceived as lacking the capability to engage in violent conflict (e.g. Assies 2003). In transboundary river basins, the availability of additional water, e.g. due to glacial melting or altered rainfall patterns due to climate change may cause conflict about which state is entitled to use the additional water. An increased availability of water can also make basins that were once considered as marginal more relevant for the riparian states, creating new water-related

interactions that can be cooperative, conflictive, or both. It is crucial that motivation and opportunity are not only conceived as objective determinants of social action but as constructed by social interaction (Ide and Fröhlich 2015). This highlights the relevance of securitization processes, the politics of scale (see below), and identity constructions.

If the linkages described above do not materialize or are not strong enough, dissatisfaction about water availability may alternatively become a driver for innovation and cooperation to diminish water stress, e.g. by more efficient water use, new sources of supply, investments into water infrastructure, or water sharing (Sadoff and Grey 2005). This not only depends on whether these options exist but also on whether they are recognized by stakeholders as options possibly leading to economic gains and a promising way out of water stress (Norman et al. 2012). In this context, the adaptive capacities for innovation and cooperation are of utmost importance. If the affected people do not take action, water issues may remain sub-critical and therefore do not trigger extraordinary responses, neither conflictive nor cooperative.

Political institutions affect the impacts of water scarcity on the probability of conflict and cooperation. They influence the ability of states to adapt their freshwater needs by mitigating possible conflicts of interest that could otherwise escalate into armed conflicts (Gizelis and Wooden 2010, Tir and Stinnett 2012). Some empirical studies indicate that water scarcity increases the likelihood of peaceful third party settlement attempts or water cooperation while high water availability may reduce the need for river treaties and related institutionalization (see section 2). Adaptation options derived at the level of the entire watershed instead of country level can offer new opportunities to address the challenges of water allocation in transboundary river systems under a changing climate (Pelt and Swart 2011), fostering joint management and benefit sharing in transboundary rivers (Dombrowsky 2010). Currently, most management agreements are only bilateral (Conca 2007, Mirumachi 2015).

Linkages in the water-security-conflict nexus

In this adaptive framework of the water-security nexus, all compartments interact and are important to produce (perceived) situations of water scarcity or abundance, which can affect (violent) conflict or cooperation along transboundary river basins through multiple pathways. While the first compartment considers the underlying systemic factors and drivers of water availability, the second compartment transforms the systemic dimensions into human values and security perceptions that guide human actions and interactions towards conflict or cooperation in the third compartment. With this approach we clarify the black box between the physical dimensions of water availability (under climate change) and the resulting social interactions, including conflict and cooperation. This puts the value-security dimensions at the core, with the demand-supply balance of water as an input and the conflict-cooperation relationship as an output. The transition between compartments is governed by the political setting, which represents institutional boundary conditions that moderate the interactions and are shaped by them as well. Water security and related discourses of securitization are influenced in a mutual way by the vulnerability to water scarcity and the vulnerability to conflict, irrespective of the causal relationships between water scarcity and conflict.

The assessment of transboundary river conflict and cooperation is complicated by the fact that such interactions are deeply embedded into “politics of scale" (Norman et al. 2012). That is, all actions and ideas of international water interactions are based on certain scales (e.g. national, local, watershed), which can complement but also contradict each other. Patterns of river-related conflict and cooperation on multiple scales can thus influence each other. Discourses that conceive the nation state as adequate for water management tend to facilitate conflict, while a preference for the regional or river basin scale more often facilitates international cooperation (Feitelson and Fischhendler 2009, Harris and Alatout 2010). E.g., the Jonglei channel was an instance of cooperation between Egypt and Sudan (international

scale) but facilitated conflict on the national scale between the Sudanese government and the inhabitants of southern Sudan (Mason et al. 2009).

In this context, the key issues can be phrased as questions to guide future research: Are changes in water scarcity strong enough to induce destabilization or even a cycle of violence? When do real-world actors attribute a loss in water value to another actor and does this provoke a response seeking compensation or revenge? Will a growing level of hostility turn violent at some point? How are intra-state conflicts at the micro or local level related to the national level and inter-state conflicts between sovereign states in different world regions? How will climate change affect the water-conflict relationship and the institutions moderating it? And how do these issues shape ongoing discourses?

6. Case studies of the water-security-conflict nexus under climate change

In the following we discuss two river basins in the context of the integrative framework of the water-security-conflict nexus for changing climatic conditions. The chosen examples are river basins in the focal regions in section 4 for which increased climate variability would add to the already existing water stress.

Nile River Basin

Water availability and climate change: Water scarcity is an issue in the Nile River Basin, which serves as the "lifeline" for an ever growing population experiencing declining water availability. In 2010, 232 million people lived in the Nile River Basin (Nile Basin Initiative 2013) and it is expected that the population in the basin will exceed 300 million people in 2025. Egypt, which is suffering from population growth, rising food prices, and political instability simultaneously, is particularly dependent on the water from the Nile as more than 95 per cent of the country's water demand has to be met by using river water, and there is only little rainfall (Elemam 2010, Link et al. 2012). About 85 per cent of the Nile water that flows into Egypt originally stems from Ethiopia, a country with a population of more than 90 million people that has hardly utilized its water resources in the past (Arsano 2010). However, the growing population and attempts to accelerate economic development in Ethiopia require an increased utilization of the river water resources. The same holds for Sudan. So far, Egypt could use Sudan's unutilized share of the 1959 Nile water agreement. But with the Sudanese demand for Nile water increasing to 32 km^3 per year by 2025, this is likely to further decrease the availability of water from the river in Egypt (Taha 2010).

However, the overall water availability in the Nile River Basin is critically dependent on the development of rainfall patterns in the Ethiopian Highlands that feed the Blue Nile. It remains to be seen how climate change will influence the amount of water in the Nile River Basin as climate models are still inconclusive with regard to the development of precipitation in the Ethiopian highlands (Stocker et al. 2014). In recent decades, the flow of the Blue Nile has increased while the flow in the White Nile has decreased, causing the overall flow to be more or less stable (Kim and Kaluarachchi 2009, Bushara and Abdelrahim 2010). Additional uncertainties are related to the role of the Sudd Swamps in South Sudan, where a considerable amount of water evaporates from the White Nile.

Evaluation and water-security discourse: The interaction of physical and socio-economic drivers leads to a greater uncertainty and thus an increased vulnerability with regard to the overall water availability. When political elites or the wider public perceive national security to be threatened by a reduced supply or an increased demand for water, they may turn to conflictive strategies to protect their interests. The affected population can pressure its government to take a harder stance in international river basin negotiations, thereby provoking water conflict (Feitelson 2002). Human security can further be adversely affected by water scarcity if livelihoods are undermined by harvest failure, inadequate sanitation, high

food prices or a harmful water quality (Deligiannis 2012) as was the case in Egypt prior to the Arab Spring in 2011. The historic asymmetric development of the riparians of the Nile has complicated the interactions. Egypt has achieved the status of a hydro-hegemon mainly due to its considerable external support in colonial times and during the construction of the Aswan High Dam (facilitated by, among others, Soviet financial support) (Allan 2009). In recent years this status has been challenged not only by the economic and demographic development of the countries further upstream but also by the possibility that the overall amount of water to be distributed in the Nile River Basin decreases.

Conflictive and cooperative responses and interactions: Highly vulnerable countries may turn to unilateral actions concerning water allocation of the Nile, which increases the potential for conflict (Link et al. 2012). This development can be countered by an increase of the joint adaptive capacities of the riparians through cooperation. The construction of large dams in the upstream countries such as the Grand Renaissance Dam in Ethiopia further adds to the difficulties concerning the allocation of Nile water as it withholds an amount of water equal to more than one annual flow rate of the river from the downstream countries (Bastawesy 2014). After completion of the dam, Ethiopia becomes a regional power in the Nile River Basin that may force Egypt to abstain from its hydro-hegemonial status and to foster basinwide cooperation instead (Gebreluel 2014), also benefitting from the concurrent weakening of the Egyptian regime. However, this requires a functioning conflict resolution mechanism that has the capacity to mediate conflicts among riparians (Wiebe 2001). Furthermore, not all cooperative projects meet expectations: e.g. the construction of the Jonglei Channel was supposed to increase the water availability and deepen cooperation over the Nile between Sudan and Egypt. But inadequate consultation and the expropriation of land holdings from local populations intensified tensions between the population in southern Sudan and the Khartoum government, finally causing the failure of the project (Mason et al. 2009).

On the other hand, there have been considerable cooperative efforts in the Nile River Basin, culminating in the founding of the Nile Basin Initiative in 1999. These have been considerably supported by external sources such as the U.S. and the World Bank who had substantial political and economic interests to support cooperation in the Nile region (Paisley and Henshaw 2013). Under the auspices of the Nile Basin Initiative there have been many cooperative projects (cf. www.nilebasin.org) and negotiations to devise a Cooperative Framework Agreement, which has so far been signed by six countries and ratified by three. So despite the fact that there are bilateral disputes about water (e.g. between Egypt and Ethiopia), there are credible efforts to reach a joint management scheme for the entire river basin.

Nexus linkages: The Nile River Basin is already challenged by a highly variable climate and it is unclear what the future effect of climate change will be on the water availability in the river basin. Even an increase in the overall water supply in the Nile River Basin may not be enough to offset the growing demand, which will place a burden on the adaptive capacities, particularly of the downstream riparians (Link et al. 2012) and increases the already high vulnerabilities to climate change in these countries (Brooks et al. 2005). The events following the Arab Spring have led to political and economic destabilization in countries like Egypt, which affects their ability to address water problems. Countries have to adjust by protecting their own interests or by cooperation. Particularly the arrangements between the key actors in the Nile River Basin (Egypt, Sudan, and Ethiopia) that have to be made once the Grand Renaissance Dam in Ethiopia is in operation provide chances for long-lasting cooperation in the region (Link and Scheffran 2015) as fundamental agreements regarding the distribution of water and energy from hydropower become necessary.

Syr Darya and Amu Darya

Water availability and climate change: In the past few years, disputes over water use and energy production have increased in the Syr Darya/Amu Darya Basin between the upstream countries Kyrgyzstan and Tajikistan and the downstream countries Kazakhstan, Turkmenistan, and Uzbekistan (Siegfried and Bernauer 2007). This has to do with the completely opposite patterns of water and energy use: As the upstream countries need to release water from reservoirs during winter to generate energy for heating, this causes floods in the downstream areas. And in summer, when water is needed for agriculture in the downstream countries, the upstream countries reduce flow rates of the rivers to replenish their reservoirs. Attempts to establish a functioning institutional setup that governs water and energy allocation in the region have so far been unsuccessful (Bernauer and Siegfried 2012). Variability in precipitation in recent years has increased the pressure on water resources and stakeholders in the region as it is expected that water shortages will become more frequent in the summer months (Sorg et al. 2014). Furthermore, replenishment from glaciers could decrease in the future, making water management by sensible use of the reservoirs ever more important.

Evaluation and water-security discourse: There has been a tendency towards securitization of water allocation issues in Central Asia (Sorg et al. 2014), which discourages coordination among the neighboring countries. Water interaction is further complicated by persistent national rivalries and frequent attacks against ethnic minorities in the respective countries. Recent attempts to address concerns for national and human security and resolve water allocation disputes that have arisen from the divergent seasonal requirements for water have mainly focused on technical solutions. However, the social and political dimensions of these issues should receive greater attention (Abdullaev et al. 2012). There has been external pressure not only to become more irrigation efficient but to switch from cotton to food crops to enhance food security.

Conflictive and cooperative responses and interactions: Talks on water allocation (Wegerich et al. 2012) are key requirements to reduce the inter-state tensions among the riparians which emerged in the past two decades. In addition to mere allocation quotas of water, a conflict resolution scheme would also need to address the issues of who gets the water, which rationale of water distribution and benefit allocation for water conservation projects is applied, and how to monitor and enforce agreements on water exchange (Deng et al. 2012, Karthe et al. 2015). There have been several attempts to design agreements between the five riparians since their independence in the early 1990s, even linking the issues of water and energy (Hodgson 2010). But the current scheme of water allocation is still based on priorities set up in the Soviet era and there has been no success in the design of a new scheme that is based on equity (Sorg et al. 2014). One key obstacle is that there is no obvious advantage to all countries for cooperation, thus the situation is perceived to be only advantageous for a riparian when a development is at the expense of another (Mosello 2008). Consequently, as there is no agreement yet that suits all countries, non-cooperation remains the common strategy.

Nexus linkages: Climate change impacts in Central Asia are expected to manifest themselves through reduced precipitation and in conjunction with increasing water demand there is an additional necessity to reach an agreement on how to share the remaining water among the riparians (Sorg et al. 2014). However, the governance structures carried over from the Soviet era and the securitization of water have created an atmosphere of distrust, in which there is little room for cooperation (Bichsel 2009). Furthermore, external pressures on the countries to increase food security or improve irrigation efficiency have a profound albeit indirect impact on the water resources as well (O'Hara 2000). There are chances for increased basinwide cooperation but only if management schemes incorporate measures to reduce governance and policy obstacles for successful climate adaptation by means of cross-sectoral integration and improved communication between stakeholders.

Comparison of interactions in the water-security-conflict nexus

	Nile River Basin	Syr Darya/Amu Darya
water availability and climate change	Water scarcity is likely to increase because of population growth and continued economic development. Implications of climate change are unclear, which increases uncertainty in the region.	Seasonal water allocation among the riparians is a key issue in the water disputes in Central Asia. Climate change is likely to reduce river replenishment, adding to the already considerable variability in water availability.
evaluation and water-security discourse	Egypt's historic role as hydro-hegemon is challenged by upstream riparians. Water scarcity can be regarded as threat to national security despite being brought about by non-political factors.	Securitization of water has prevented cooperation among riparians. Management schemes need to incorporate more aspects than merely technical issues. Governance and hydro-diplomacy have received much less attention than water allocation.
conflict and cooperation	Dam construction is considered to be a threat to downstream countries. Nile Basin Initiative provides basis for basinwide cooperation.	Attempts to devise a basinwide agreement on water (possibly even linked to energy) have been unsuccessful. Non-cooperation remains the predominant strategy.
nexus linkages	Climate change reduces adaptive capacities and increases vulnerabilities of the riparians. The Grand Renaissance Dam in Ethiopia necessitates new agreements. This is a chance for long-term cooperation but can also end in a conflictive way.	Decreasing precipitation and outdated governance structures have yet prevented the successful setup of cooperative structures. These would have to consider governance and equity issues as well as technical and engineering aspects.

Table 2: Comparison of interactions in the water-security-conflict nexus in the Nile River and Syr Darya/Amu Darya basins.

Depending on the setting of the given transboundary river basin, the interactions of the stakeholders within the water-security-conflict nexus can vary considerably. The two river basins, to which the framework has been applied above, are compared in Table 2. In both cases climate change is an additional driver that adds to the already existing challenges for an equitable water allocation, which are based on historic developments in the 20th century. There are differences when it comes to current trust or distrust among riparians but for successful long-term management, the conflictive structures have to be overcome. Also, it is noted that the regions do not exist isolated but are embedded in a global economy in which governmental and non-governmental organizations and foreign countries and institutions also considerably influence the boundary conditions for cooperation or conflict. The greatest chances for stable cooperation are attributed to strategies that involve the linking of several sectors and consider the bigger picture besides the water sector itself (Gebreluel 2014, Sorg et al. 2014).

7. Conclusion and outlook: From environmental conflict to environmental peace perspectives

Transcending simplified relationships, this assessment analyzes water conflict and cooperation as a complex issue. The review first provided an overview of the existing definitions and datasets and the results of statistical studies. As there are many possible paths linking variables of environmental change to water conflicts and cooperation, we looked at factors and pathways that affect whether transboundary water issues are resolved cooperatively or through conflict. Past conflicts not only featured a physical and a socio-economic dimension but also included cultural aspects, highlighting the fundamental role of water in people's lives in all parts of the world. Climatic change, together with concurrent developments of growing populations, water-related inequalities, and economic development, have the potential of increasing water stress to critical levels beyond existing adaptive capacities. Consequentially, states are more likely disagree about water use, distribution and control. Particularly in transboundary river basins, water-related conflicts often exceed the mere issue of which riparian gets which share of the available water.

Research on the relationship between transboundary rivers, water availability, conflict and cooperation is still developing. To structure the existing research results a conceptual framework has been developed that implements water security pathways and reflects the complexity and variety of water disputes for all possible spatial extents. This framework not only considers the physical aspects of water disputes but also incorporates the possible feedbacks between environmental and social change, the role of social structures affecting water demand and supply, and possible responses to increased water scarcity.

A closer look at cases of conflict and cooperation around two transboundary river basins that are current or likely future hot spots of water-related disputes supports the notion of the complex interaction between physical and social variables in most water disputes. Despite the fundamental differences in water stress in the various parts of the world, the actual allocation of water is rarely the heart of the conflict. Usually, there are accompanying political considerations that manifest themselves in concurrent struggles over hegemonial status, the production of electric power, the distribution of water-related services, the maintenance of water quality standards, or the preservation of certain (e.g. traditional, nationalist or modernist) values. It would be naïve to think that transboundary water-related conflicts could be resolved simply by making more water available (Bichsel 2009), as demonstrated by the Israeli-Palestinian water conflict, where increasing water availability due to desalination and wastewater recycling did not facilitate conflict transformation (Aviram et al. 2014). This demonstrates that the framework of the water-security-conflict nexus needs to be embedded into wider political, societal, economic, and cultural structures and discourses.

While the environmental conflict perspective identifies water scarcity and competition as drivers of sometimes violent conflict over shared river basins, the environmental peace perspective suggests that shared environmental problems (such as water scarcity or pollution) provide incentives for hostile states to cooperate in order to realize common gains (Conca 2002). These different perspectives play important roles in most water disputes and have to be considered simultaneously to fully understand and resolve them effectively. Recent research activities into water conflicts have paid increasing attention to the social and cultural dimensions of the disputes, providing valuable insights to improve the understanding of this nexus in order to increase the likelihood of successful mediation of water conflicts in the future.

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Appendix

study	**river system**	**resolution/ unit of analysis**	**independent variables**	**type of conflict or cooperation**	**main finding**
Algamal 2011	various African rivers	country level	climate change, precipitation	water allocation among riparians	high water interdependency can promote cooperation but also increase conflict risk if factors are lumped
Ashton 2002	various African rivers	intercommunal to country level	population growth, economic setting, water scarcity	water allocation among riparians at various scales	promote principles of equity, particular attention to water demand management
Bernauer et al. 2012	Jordan	sub-national level, country level	climate change	conflict events related to water	Water Events Scale records time, location, and intensity of water related events and actors
Bhaduri et al. 2011	Volta River	country level	climate change	water allocation among riparians	cooperation increases water availability for agriculture without losses in other areas
Dinar & Wolf 1994	Nile, Jordan	country level	water demand, political setting	interbasin water trade between neighboring countries	water trade may increase regional welfare, which may be preferred alternative
Drake 2007	Euph-rates, Jordan,	country level	precipitation, population growth,	water allocations among	water is only one factor influencing conflict in this region besides many

	Nile Rivers		economic development, technological development, political fragmentation	riparians	other socio-economic issues
Feitelson et al. 2012	Jordan	country level	climate variables, extreme events, energy use, agriculture, infrastructure, water policy	groundwater allocation between Israel and Palestine	climate change affects livelihoods mainly in remote areas and only little in urban areas, even with water reallocation
Frey 2009	Euph-rates, Jordan, Nile Rivers	country level	population growth, economic development	water allocation among riparians	the presented power-analytic framework is basis for a predictive theory of conflict on transnational water
Gruen 2000	Tigris-Euph-rates	country level	water treaties, security issues	link between water and security issues	Strategies to advance riparians' interests are reviewed and proposals to foster peace are examined.
Hamandawana et al. 2011	Okavan-go River	country level	water flow, precipitation, runoff, population	water allocation among riparians	application of a hypergame theoretical analysis allows the design of allocation arrangements to resolve conflict
Phillips 2012	Jordan River	country level	economic growth, environmental and ecosystem services	unilateral action instead of cooperation	riparians are likely to prefer unilateral action despite advantages of cooperation
Shuval 2000	Jordan River	country level	water scarcity, water allocation schemes	water allocation among riparians in the context of the geopolitical setting	possibility to account for security concerns and riparians' needs in a tri-lateral water arrangement
Warner 2012	Nile River	country level	water availability, hydro-hegemony, water securitization	water wars or water peace in its discursive context	persistent discourse that there is neither water war nor water peace
Wiebe 2001	Nile River	country level	water quality, demographic development, economic activities	diminished water quality as driver of conflict among water users	An effective NBI needs to devise an explicit and efficient basin-wide treaty

Table S1: Studies on the water-security nexus in transboundary river systems in Africa and the Middle East.

study	**river system**	**resolution/ unit of analysis**	**independent variables**	**type of conflict or cooperation**	**main finding**
Abdullaev	Syr	country level	historical	influence of	Water management

& Atabaeva 2012	Darya, Amu Darya		assessment of water management	governance structures on effective water management	shifts from technical issues to social and political aspects. Coordination of reforms helps reduce competition
Bernauer & Siegfried 2012	Syr Darya	country level	climate change, runoff, institutions and management	water allocation among riparians	a climate change induced militarized inter-state conflict over water is unlikely
Chakrabor-ty & Serageldin 2004	Indus, Ganges, Brahma putra Rivers	country level	water availability, population, preservation of water quality	treaties governing water allocation among neighboring countries	plans opposing water development measures create insecurities in people, increasing the chance of conflict
Deng et al. 2012	Syr Darya, Amu Darya, Aral Sea	country level	runoff, water availability, population, water consumption	water allocation among riparians	resolution of water conflicts requires four fundamental tasks, linking water to energy issues and ecological and social aspects
Kaiser Khan 2012	Ganges River	country level	water abundance, demographic growth, economic growth	upstream water use impacts on downstream countries	integrated water management with technological progress is necessary for sustainable water sharing among riparians
Kirby et al. 2010	Mekong River	country level	water abundance, flow, climate change, demographic growth, economic output, institutional setting	population pressure necessitates generally unregulated development	tensions increase with population growth, resource use, development, and extended food demand
Onishi 2007	Mekong River	country level	topography, hydrology, demographic growth, economic growth	water hegemony	China compromises with other riparians despite its dominant geographic position
Pearse-Smith 2012	Mekong River	country level	hydropower development	influence on ecological integrity and subsequently on human livelihoods	armed interstate conflict in the Mekong Basin is unlikely in the foreseeable future
Rahaman 2012	Ganges, Brahma putra Rivers	country level	hydropower development	heterogenious distribution of profits from hydropower development bears conflict potential	unilateral development and diversion plans by China and India likely causes conflict and possible disaster
Siegfried et al. 2012	Syr Darya	110 individual sub-catchments	climate change, hydrology	water allocation among riparians	reliance on increased water availability to solve allocation problems is a risky strategy

		of the Syr Darya			
Wegerich & Kazbekov 2012	Syr Darya	country level	hydrology, institutions and management	political setting affects effectiveness of river management	acknowledgement of polycentric pragmatism may lift deadlock of negotiations and ease tensions
Wegerich et al. 2012	Syr Darya	meso-level	hydrology, institutions and management	simultaneous occurrence of conflict and cooperation though at different scales	assessments of conflict and cooperation need to consider different levels of water management hierarchy
Wirsing 2007	Indus, Ganges, Brahma putra Rivers	intrastate vs. interstate	population, economic development, water demand, water use efficiency	challenges arising from scale, effectiveness and scheme of water management	intra-state issues are as important as international ones when moving towards joint water management
Zhao 2009	Huaihe River	province	benefit allocation	water allocation among riparians	Assessment indicates that a model of collective cooperation and benefit reallocation is superior to a model of proportional sharing

Table S2: Studies on the water-security nexus in transboundary river systems in Central, South and Southeast Asia.

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