Thematic Week: Water Economics and Financing

Thematic Axis: Water Markets

Title: Future Scenarios: the Impact of Climate Change and Droughts on Transboundary Water Dispute and Management

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Abstract:

Future climate scenarios predict a general increase in the temporal variability of hydroclimatic conditions. With water demand on the rise at the same time, water systems will likely become less reliable and more vulnerable to the occurrence of extreme events such as droughts. The paper explores how future changes in hydroclimatic variability and drought occurrence may influence the hydropolitics of transboundary rivers and discusses the challenge of integrated management of international river basins. Analyses are based on global data of past events of conflict and cooperation in international river basins from the Transboundary Freshwater Dispute Database of Oregon State University, and on hydroclimatic variables for the basins. The records suggest that drought has been a major hydrological event to influence hydropolitics worldwide. A model classifying risk for conflict explores and confirms a strong relevance of hydroclimate, in particular its variability, for potential conflict. While global climate and hydrological models do not yet produce reliable predictions of future changes to drought events, climate scenarios generally suggest that water stress will increase in many of the basins that have experienced conflict before. The likelihood for many basins in climatic transition regions to experience changes from moderate to severe water scarcity suggests an urgent need for robust water allocation agreements for transboundary rivers. Formulating such agreements is difficult in a situation in which water resources management can no longer rely on assumptions of stationarity to predict water availability and in which future water demand is highly uncertain.

Keywords: Climate change, drought, transboudary rivers, conflict and cooperation

Introduction

Good practice in integrated water management includes the prediction and planning of future water supply and demand. Current practice to fulfil this task is to use climate change scenarios as well as predictions of water demand to assess potential changes to water availability and the necessity for water management measures. There are several difficulties involved, but particularly challenging are the great uncertainties in both types of scenarios. Nevertheless, there is enough agreement among studies on the topic for the IPCC (2008) to conclude that:"

- Climate change affects existing water infrastructure and management practices because it will aggravate the impact of other stresses such as population growth, changing economic activity, landuse change and urbanisation, etc. which will increase water demand.
- Current management practices may not be robust enough to cope with the impacts of climate change on water supply, flood risk, health, agriculture, energy and aquatic ecosystems."

The bases of these conclusions are the results of global climate models driven by greenhouse gas-forced climate change scenarios together with population and development predictions. The latest models now agree in the prediction of not only an increase in global temperatures but also an increasing variability in the distributions of temperature and precipitation (IPCC, 2008). Even regions that are predicted to become wetter on average may then experience higher variability in occurrence and severity of extreme wet and dry periods. This increased climatic variability in time and space can be expected to propagate to natural water supplies: both surface water and groundwater bodies. Due to the strong biases in the water fluxes predicted by Climate Models, however, few studies have attempted to investigate related changes in floods and droughts in more detail. Closing this research gap is the aim of current endeavours such as the EU-funded integrated project WATCH (http://www.eu-watch.org/).

Equally uncertain are future developments in water demand. Generally, increases are expected, particularly in fast developing regions, since water demand is strongly driven by population and economic activity. Scenario simulation experiments suggest that in many regions in the world population growth and increasing water use has the potential to outweigh climate change as a factor of increasing water stress (e.g. Vörösmarty et al., 2000; Alcamo et al., 2007).

The task to design robust water management and allocation schemes under these prospects is difficult in one jurisdiction, but it is even more challenging where multiple jurisdictions are involved. Therefore, the consideration of climate change impacts on river flow in international treaties about water allocation along transboundary rivers has been either absent or formulated very vague and only qualitatively. However, there are over 260 international river basins worldwide, which cover more than 45% of the land surface and affect more than 40% of the world's population (Wolf, et al. 1999). In many of these basins there have been political disputes, but there also has been an amazing amount of cooperation (Wolf et al., 2003). Official agreements between two or more countries were signed or negotiated in more and more of these basins in the past decades (Dinar and Dinar, 2005). The exact reasons for entering a treaty vary and systematic factors for success or failure of a treaty are still a topic of research. However, there is evidence that water scarcity, particularly moderate scarcity, is conducive to cooperation, a phenomenon termed "scarperation" by Dinar and Dinar (2005). One could therefore argue that under the pressure of changing water demand and availability, according to the theory of scarperation, it can be expected that more cooperation and treaties will be negotiated in previously water-abundant river basins, while cooperation will become more difficult in regions that change from moderate to more severe water scarcity.

While recent studies on hydropolitics have focused on *permanent* water scarcity and water stress as a factor governing general relations, the question how treaties and international water relations can be made robust enough to deal with the expected increasing variability of *temporary* water shortages and surpluses (droughts and floods) has received less attention. However, I argue that to guarantee sustainable international relations these temporary stress situations also require agreements between countries. To elucidate how temporary stress in times of floods and droughts has influenced conflicting interests and/or cooperation and management of transboundary waters in the past will be useful to assess the significance of temporary water stress situations in transboundary rivers and evaluate the need for both: prediction of future occurrences of hydrological extremes and prevention of related disputes through adequate agreements.

This paper focuses on drought situations and hydroclimatic variability (as a proxy for reliability) that influenced hydropolitics in international river basins in the past. The aim is furthermore to assess available climate change scenario predictions for basins where drought has seemed to play a role in the past. Difficulties are discussed that hamper multidisciplinary analyses and modelling. These include scaling issues (country and time-aggregate info vs river, basin, aquifer an temporally high resolution) as well data availability and quality, and indices and conventions used in the different disciplines of natural sciences and political and social sciences.

Data base of multidisciplinary indices

To study the link between hydropolitics and hydroclimate, adequate data bases of both are needed. In the Transboundary Freshwater Dispute Database (TFDD) at Oregon State University two political datasets are linked to the world's international river basins: an international freshwater treaties dataset (published as an atlas by UNEP & OSU, 2002) and a dataset of reported political events of water-related political conflict and cooperation (Yoffe et al., 2004). The latter dataset covers the period from 1948 to 2000. All political events relate to water as a scarce or consumable resource and were coded on a scale of conflict and cooperation. From its introduction within the Basins-At-Risk project, this scale is now known as the BAR-scale and runs from –7 (most conflictive) over 0 (neutral interaction) to +7 (most cooperative). Details on methodology and data sources can be found at www.transboundarywaters.osu.edu.

Hydroclimatic conditions that may influence a region's risk for conflict or its potential for cooperation over freshwater can be described by many different variables. Although demand is difficult to determine, long-term average estimates are derived and published routinely for most countries worldwide. Water stress indices (usually water availability/population) have become common variables in global environmental assessments carried out at the country level. Economic and political variables are also commonly used indicators for countries' economic and institutional capacity to deal with environmental stress. The use of these common freshwater indices as explanatory variables in statistical analyses is problematic as it assumes that the variability of the individual factors in time and space is negligible. Though the average water availability situation of a country may indicate potential water stress, the source itself (in the case of this study: the river) is the subject of dispute or cooperation. Countries may cooperate well over one shared river, but not well over another or with another riparian country. Hence, the geographic unit of analysis must relate to the river basin. Likewise, in times of rapid development and/or climate and environmental change or even just during a drought period, average long-term indices can also be problematic.

Assessments of conflict and cooperation over transboundary rivers consequently require consideration of spatial and temporal variability and change. Therefore, a set of hydroclimatic and hydrologic variables was specifically established for the global international river basins as well as for the shares of individual countries of these basins (called 'basin-country-polygons': BCPs) (Stahl, 2007). The variables describe average conditions as well as the variability and extremes in space and over time (Table 1) and were designed for integrated multidisciplinary studies. They were derived from global gridded climate data products and from at-station streamflow records.

Table 1: Indices for global international basins of the TFDD (after Stahl, 2007)

Variable	Description	Data Source
Hydroclimatic		
A	Index of Aridity (mean annual precipitation/potential evapotranspiration)	UNEP (Ahn-Tateishi, 1994)
P	Mean annual precipitation	CRU (New et al., 2000)
CVPs	Spatial variability: coefficient of variation of mean annual precipitation	CRU
CVPt	Inter-annual variability: coefficient of variation of annual precipitation 1948 to 1998	CRU
SP	Intra-annual variability: seasonality index of mean monthly precipitation	CRU
q	Specific discharge (mean annual discharge/basin area)	GRDC (Stahl, 2007)
CVQ	Inter-annual variability: coefficient of variation of annual mean discharge.	GRDC
SQ	Intra-annual variability: seasonality index of mean monthly discharge.	GRDC
Qz	Fraction of time without discharge	GRDC
Geographic, socio-economic, political (details in Yoffe et al., 2004)		
ncountries	Number of riparian countries	TFDD
dams	Number of major dams	World Commission of Dams
Barea	Basin area	TFDD
Pop	Population density	LandScan
GDP	Average GDP per capita	World Bank
DA	Average index of democracy	PolityIV

Methods

To investigate the role of drought events in international water relations, first the texts of the international events and treaties database of the TFDD were mined for the mentioning of “drought”. In addition, where sufficient hydrological records were available, drought indices calculated from river flow (Stahl, 2008) that preceded conflictive events were used to evaluate whether the drought was really a hydroclimatic event or whether it was a “man-made” water allocation problem.

Second, the role of hydroclimatic variability among a more complex set of drivers was explored with a classification and regression tree (CART) approach to model the likelihood of the occurrence of conflict in a basin with a given combination of hydroclimatic and socioeconomic factors. The Basins-At-Risk Analysis by Wolf et al. (2003), a further study by Stahl (2005), and other investigations have shown that not one single factor but combinations of several influences are related to conflict and cooperation, and that relations between hydroclimatic factors and political events along the conflict scale are not linear. The method accounts for the multiple conjunctional causality known to govern international relations. This means that different combinations of factors can lead to the same outcome and the same factor can have a different effect under different circumstances. The model also allows the inclusion of numeric as well as categorical variables and these do not have to be normally distributed, and can be interrelated.

A classification tree predicts a single categorical response variable (here: conflict = 1 and no conflict = 0) by the values of a set of predictor (explanatory) variables. Constructed by recursive partitioning of a learning sample of class values (response variable) and predictors, the tree finally represents a collection of many decision rules displayed in the form of a binary tree. Each point in the tree where a decision has to be made is called a "node" with true or false leading either to the next decision rule or to a "terminal node", where a classification is assigned. The rules take the form of: "if Index of Aridity $A \geq 1.5$ and population density $Pop \geq 100$ people/km2 and the river is ephemeral and …, then basin x is most likely in Class 1 (conflict)". For cases with missing data in the predictor values alternative rules using available predictors (surrogate splitters) are found. In this study the response variable was based on the political events from 1950-2000 and describes whether there has ever been a conflict (events with a negative BAR code) or never been a conflict (no events with a negative BAR code) in a basin. The predictor variables consist of all variables listed in Table 1. In a standard procedure, first a maximum classification tree was fitted to the learning sample of 123 basins which have records of political events. The tree was then pruned to a cost-complexity optimized tree and subjected to a 20-fold cross-validation. Finally, the optimum tree rules were applied to the basins without political data to predict their risk for conflict.

To assess future changes to the conflictive potential in international basins, predicted changes in the potential hydroclimatic drivers such as droughts, hydroclimatic variability in time and space, and water demand, were derived from the literature. Unfortunately, however, global predictions of future hydrologic extremes such as droughts are unavailable at this time. Related to the emerging availability of higher spatial and temporal resolution output of regional climate models, future changes in hydroclimatic variability is also still an emerging topic of research. As a surrogate, published maps of predicted changes in average runoff by Milly et al. (2005) and water availability and withdrawals (as an indicator of water demand) by Alcamo et al. (2007) were therefore used for a qualitative assessment in this study. Similarly, published maps of predicted changes in water withdrawals by Alcamo et al., 2007 were used. This procedure assumes that a decrease in general water availability is related to increased variability and occurrence of droughts.

Results

Drought-related political events

The issue of drought appears most often in the documentations of dispute and negotiation in the Jordan River Basin. However, there are text-records from all over the world stating drought as an issue in international relations over water. Some examples are summarized in Table 2. The table only lists events that were clearly linked to a hydrological drought as identified in Stahl (2007). Events where drought was 'man-made', e.g through reservoir operation in the upstream country, were excluded. An example of such an event was a complaint by Bangladesh about the Farraka Barrage operation in India dropping water levels and hence "creating drought".

Table 2: Droughts linked to conflict and cooperation (modified from Stahl, 2007)

Region	River Basin	Hydroclimatic Event	Linked political event
North America	Colorado	Drought in the 1960s	Dispute over salinity (1972)
		Drought in the early 90s, low annual floods	Dispute over renegotiation of treaty because of pollution and over allocation
Southern Europe	Guadiana	Drought in the early 1990s	Dispute over renegotiation of treaty because of pollution and over allocation
Southern African Region	Incomati	Drought 1982	Trilateral negotiations on water sharing

West Africa	Senegal	Trend and multi-year droughts	Conflict over projects and water rights in the 1990s
Middle East	Jordan	Moderate drought in 1994 Drought in 1999	Raising the need for treaty amendments conflict, particularly between Israel and Jordan
Southeast Asia	Mekong	Negative trend of annual flows and droughts in early 1990s	Increased political activity; drought of 1994 is the context for negotiations on river diversions for irrigation in Thailand

Most of the cases summarized in the table have received attention in literature and even in the media. In North America, the USA and Mexico share the Colorado and Rio Grande Rivers. Both have been the issue of considerable dispute, negotiation, and cooperation. In the Colorado River, droughts in the 1960s and in the early 1990s were followed by political events. In the Rio Grande basin, consecutive years of drought in the late 1990s and early 2000s were the cause for dispute, because Mexico could not deliver the agreed discharge (after taking the drought escape clause included in the treaty). The water-related international relations between Spain and Portugal have been strained by consecutive drought years in the 1990s. Recent discharge data was unavailable for any of the transboundary rivers in the region (Guadiana, Duero and Minho) through the GRDC, but the climatic origin of the droughts are documented. In the Incomati River Basin both, floods and droughts, have started and greatly influenced negotiations. After the 1982/83 drought, when the Incomati had fallen dry in Mozambique, South Africa agreed to guarantee a minimum flow. Droughts that followed have challenged this agreement. In the Sahel region annual precipitation and runoff have decreased continuously since the 1970s. This has put additional stress on the international relations in the Senegal River. After having closed several treaties in the 1960s several incidents of verbal and violent dispute were reported.

Much has been written on water disputes over the Jordan River and its tributaries and political motivation and relative water scarcity are clearly main drivers for most of the water-related interactions between Israel and its neighbours. In the many political events about the Jordan River in the political event database of the TFDD, drought is mentioned several times as a concern and issue pressing for cooperation. The first mentioning can be found in 1991 and then in 1994, right after years with low flow according to the discharge data available. The database entry is a record of public concern that drought conditions should be considered and included in any future treaties over water sharing. The next mentioning of drought can be found in 1998/99, when Israel announced that due to drought it can only provide 40% of the annual allocation of the Yarmuk River water (a tributary to the lower Jordan). Jordan initially rejected any change in the terms of the treaty and a long process of negotiations started to solve the crisis.

In the records for the Mekong basin, finally, it can be found that the drought of 1994 was the context for negotiations on river diversions for irrigation in Thailand. Droughts in the early 1990s are visible in the hydrographs of the Mekong and its tributaries.

Model of risk for conflict

The CART analysis produced a classification tree with 14 nodes (Figure 1). It can be read in the same manner as a decision tree: if the spatial variability of precipitation (PCVS) in a basin is lower than 0.47 then further classification follows the rule at node 2, else it follows the one at node 12, etc. The figure also shows the distribution of classes at each terminal node and the number of basins classified at each terminal node. The tree correctly classifies 90.2% of all basins with no conflict (65 of 72) and 94% of all basins with conflict (47 of 50) in the learning sample. In the 20-

fold cross-validation procedure, on average 64% of basins with no conflict and 70% of basins with conflict are classified correctly.

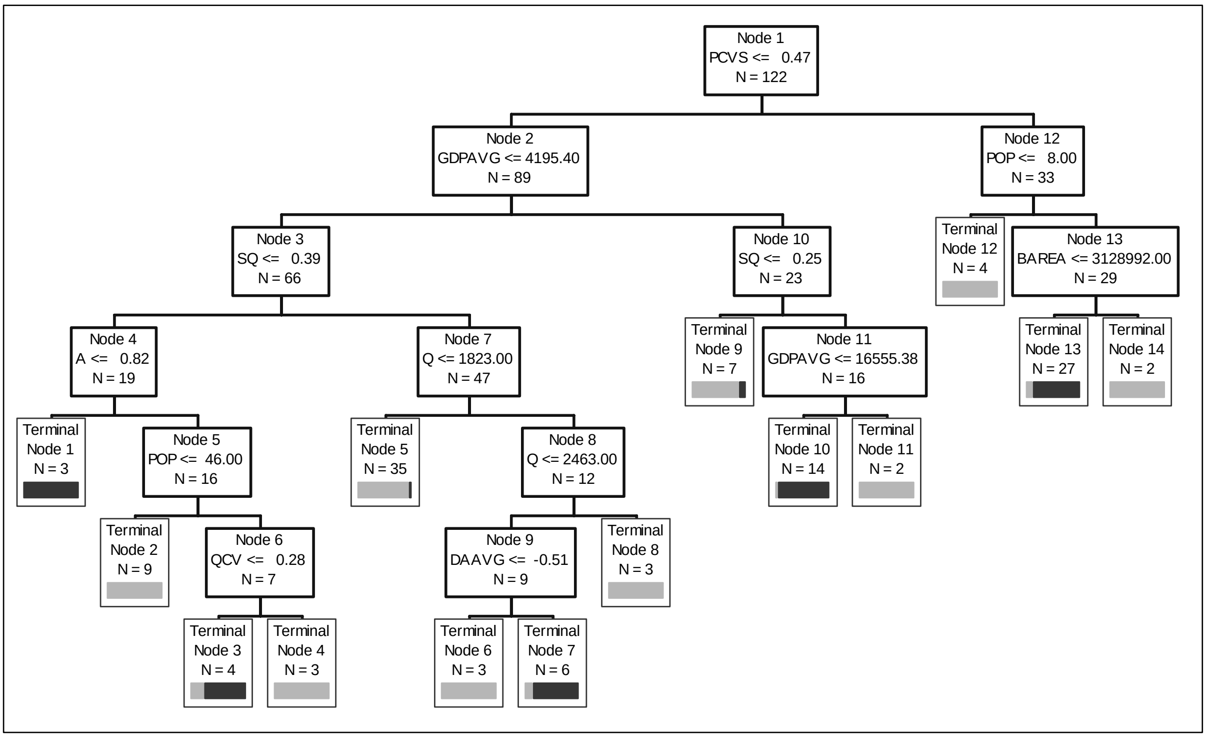

Figure 1: Optimum classification tree with class distribution at the terminal nodes (dark grey = basins with conflict, light grey = basins with no conflict)(from Stahl, 2007)

The most important splitters are seasonality of discharge, spatial variability of precipitation, GDP, and population density. Many of the well-known conflictive basins (e.g. Jordan, Tigris) were classified by a high variability of precipitation and a moderate (not very low) population density. The result confirms the strong relevance of the hydroclimate, in particular the difficulty of transboundary hydropolitics to deal with its variability.

Figure 2 shows the result of the application of the derived classification rules to all basins, including those for which no political data was available. For the latter basins, the result from this application could be interpreted as prediction of the risk for conflict or potential for cooperation. Most basins with risk for conflict are located in the dry or subtropical regions of Africa. In North America all transboundary rivers of the West and in South America the La Plata basin are classified as potentially conflictive. The same applies to rivers in southern Europe, the Middle East and Southern and Southeast Asia.

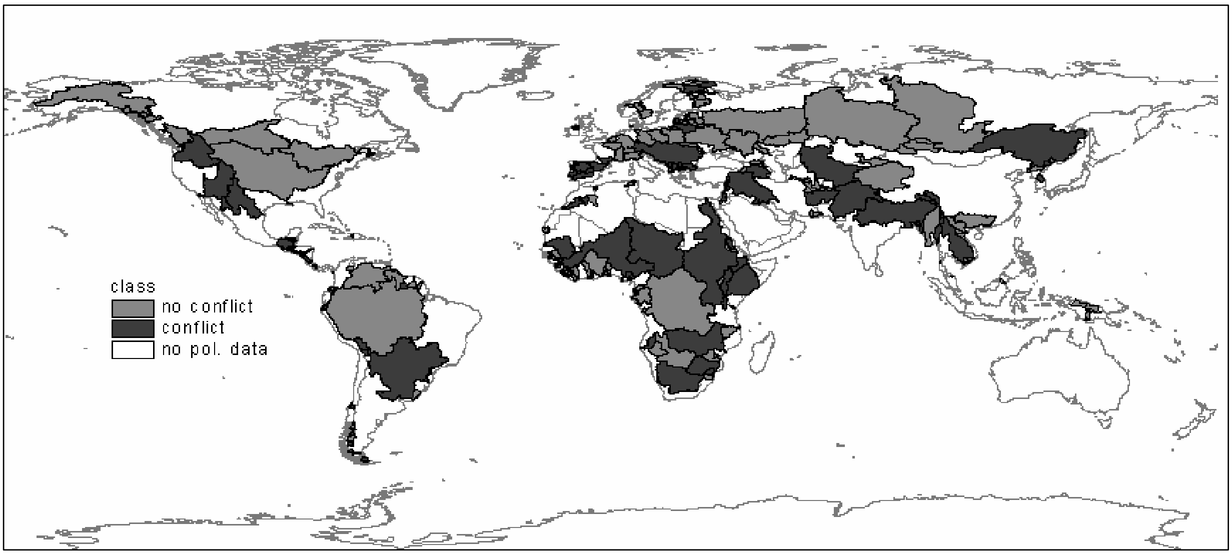

Figure 2: Classification tree model application to all global international basins (from Stahl, 2007)

Future Predictions of drought and water demand

Table 3 summarizes predictions from two studies that presented expected changes for the middle of this century compared to a reference period in the 20th century: Milly et al. (2005) used ensembles from many climate models and a simple hydrological model with bias correction; Alcamo et al. (2007) used output from two climate models to drive a global hydrological model that also simulates scenarios of future water withdrawals. Due to the differences in the two studies with respect to climate models, hydrological model, validation data set, reference period, greenhouse gas forcing and economic scenarios, etc., only the direction of the predicted change for the international basins of interest was extracted from the published maps.

In North America, except for the Colorado River Basin, for which drier conditions are predicted, predictions of water availability and water use differ among the studies. In Central America there are similar differences. The La Plata Basin in South America is predicted to experience wetter conditions, but also an increase in water withdrawals. The river and its tributaries is already heavily used for hydropower and with predictions of a wetter climate additional developments are likely not to be slowed down.

Predictions also agree on future drier conditions in southern Europe. A similar continental scale modelling study by Lehner et al. (2005) specifically addressed changes in floods and droughts. The results indicated that climate change will be the major factor to increase the risk for drought in southwest Europe, for example in the Guadiana Basin, which has given reason for dispute between Portugal and Spain. In southeast Europe, however, increasing water use may cause similar stresses.

Some of the highly disputed rivers in the Middle East, the Jordan Basin and the Tigris-Euphrates River System lie within an area where climate models disagree. The majority of models predict drier conditions, but some predict wetter conditions at least for the Tigris-Euphrates Basin. According to the data sources, water scarcity in the Jordan Basin will be further exacerbated by increasing water use. Similarly mixed predictions exist for the Aral Sea Basin, where major changes in land and water use in the last decades have contributed if not caused strong reductions of inflows and major shoreline recession.

Table 3: Predicted changes in international basins with either a history or risk of conflict

Region	International River Basin	Model predictions for 2050 compared to 20th Century			
		Milly et al. (2005)	Alcamo et al. (2007)		
		Annual runoff	Annual water availability	Increase of dry extremes	Future withdrawals
North America	Columbia	Decrease	Increase	no	Increase
	Colorado	Decrease	Decrease	yes	Decrease
	Rio Grande	Decrease	Increase	no	Mixed
Central America	all	Decrease	Increase	no	Increase
South America	La Plata	Increase	Increase	no	Increase
Southwest Europe	Duero, Guadiana, etc.	Decrease	Decrease	yes	Decrease
Southeast Europe	Lower Danube tributaries, etc.	Decrease	Decrease	yes	Increase
Middle East	Jordan	Decrease	Decrease	yes	Increase
	Tigris-Euphrates	Decrease	Increase	no	Decrease
Central Asia	Aral Sea	Decrease	Increase	no	Mixed
South Asia	Indus, Ganges, etc. (Rivers originating from Himalayas)	Increase (decrease in headwaters)	Increase	no	Mixed, Increase
Southeast Asia	Mekong, Salween, etc.	Increase	Mixed	yes	Increase
East Asia	Amur	Increase	Increase	no	Increase
West Africa	Senegal	Decrease	Increase	possibly	Increase
East Africa	Nile	Increase (decrease in headwaters)	Increase	possibly	Mostly Increase
Southern African Region	Orange, Incomati, etc.	Decrease	West: decrease East: increase	yes no	Increase

Particularly challenging to predict are the rivers draining the Himalaya Mountains towards the south. Future changes in both major sources of water, the monsoon and the snow and glacier melt, are very uncertain and difficult to model and predict. A confusing situation is also that as glaciers recede they will for a certain time period contribute more meltwater before they become too small to contribute significantly to streamflow. It is and will continue to be tempting for upstream countries to take advantage of this only water source during the dry season. Although generally wetter conditions are predicted for southeast Asia, droughts in the region are related to climatic fluctuations and monsoon failure that may become more common. In addition, the region's development potential also suggests increased water use.

While all scenario predictions suggest an increase in water stress and droughts in the western part of southern Africa, predictions for transboundary rivers with a history of conflict such as the Incomati differ. The same applies to the Senegal in Western Africa. While major parts of the multi-country Nile Basin are expected to become wetter, scenario calculations for some of the highland headwater areas in the already water stressed upstream countries vary. Water demand can be expected to increase in most of Africa.

Discussion

In the past, droughts seem to have had considerable influence on hydropolitics in international river basins. All examples of events of conflict or cooperation analysed in this study included indications of a two-fold drought-related reason for political interaction: increasing water stress and a triggering hydrologic event. Identifying a trend and/or the triggering hydrologic event was usually possible where streamflow records were available. Often, smaller droughts occurred first, and a more severe one that followed (likely exacerbated by increased water use in one or both countries) then provoked some form of interaction among the affected riparian countries. In many of the examples mentioned here, drought seems to have caused not only conflict but also initiated cooperation. However, the absolute number of available examples of hydropolitical events linked to drought in the TFDD is low and the data base contains no information on the further progression of international relations in the individual cases. A detailed analysis of the chronology of drought and following conflicts or negotiations would require a search for additional documents and data on each individual case.

Another problem is that recent hydropolitical and hydroclimatic records are missing. However, many severe droughts around the world occurred in recent years. The TFDD is currently being updated, but in general, University-held data bases such as the TFDD, are often established through a 3-year project grant and due to the lack of funding it is hence difficult to maintain and update them beyond the duration of the project. Streamflow records, although usually collected by and held at government agencies (with tax money) are much too often not freely available. The few international data bases of streamflow records that do exist stem from one-time collations and are hence dated. The availability of climatic data is slightly better, in part because they are easier to interpolate in space over a large region than hydrological data and agencies find it easier to provide such derived ‘data products’ for free. The availability, however, may also be a result of better concerted efforts of the climate research community. The lack of recent streamflow data, however, clearly hinders not only progress in coupled land surface model validation and improvement, but in this case makes it difficult to separate natural, climatic drought periods from water use or allocation driven water shortages. However, such a separation is crucial for an analysis of how the two interact to stress agreements and international relations in international river basins.

Conflict over transboundary river water has mainly happened in climatic transition regions (e.g. semi-arid climate). These regions, which experience a higher variability of water availability from year to year, are also prone to more extensive droughts. The assessment of future changes in hydroclimate and water demand in the basins that have either experienced conflict in the past or were classified by the CART model to be at risk, further shows that they are located either in regions for which increasing water stress is expected or in regions where climate models predict contrasting changes. Additional uncertainties in future water resources predictions result from the use of different scenarios of greenhouse-gas emissions and economic development, different climate models and different hydrological models. Climate model output used in a river basin hydrolgical model usually consists of an average for a large area and is often heavily biased (i.e. precipitation amounts deviate strongly from the observed amounts). While a uniform bias can be corrected, changes in temporal and spatial variability of climate parameters are more difficult to take into account in most hydrological impact studies. According to IPCC (2007 and 2008) this leads to an underestimation of future floods, droughts and water requirements. The study by Alcamo et al. (2007) is one of the very few global studies that considered changes in the low percentiles of runoff. However, they used the so-called “delta change” approach, in which the general temporal patterns in driving climate (wet and dry spells) will remain the same as in the past, just at a different mean level. Therefore, changes in seasonal variability, drought duration, etc., are not realistic. Additionally, they only assess annual streamflow totals. Many agreements between riparian countries of transboundary rivers, however, relate to seasonal flows.

Traditionally, water allocation schemes and hence also treaties and agreements for shared water use have relied on quantities of water to be delivered in regular intervals. Before agreeing on such deliveries often a frequency analysis of past streamflow time series is carried out. Such an analysis provides return periods of certain extreme flows (e.g. low flow quantities). Milly et al., (2007) argue that climate change is invalidating the assumption of stationarity, which underlies such an approach, which is still standard procedure in water resources planning today. However, the alternative of estimating future extremes using climate and hydrological model ensembles is presently much more complex and computationally costly.

Conclusions

While aridity is a permanent climatic condition, drought is an infrequent and temporary phenomenon. As such, drought is particularly challenging for integrated water resources management. By demonstrating the role of drought in past conflicts and the importance of hydrological variability among other factors that may contribute to critical political situations in international river basins, this paper elucidates that the challenge of drought management includes hydropolitics in transboundary rivers. While the TFDD entries suggest that drought occurrence exerts an important influence on hydropolitics, it is not straightforward how to prepare for it. One reason is that future extremes are difficult to predict and highly uncertain and it is hence difficult to determine an envelope of potential future events except with sophisticated modelling experiments driven with different climate scenarios. Another reason is the difficulty to estimate future water demand, which can exacerbate a climatic water deficit. At the moment, water demand is often modelled as a function of population and economic activity. This relation, however, may change with technological development.

Climate change scenarios predict an increase of water stress in areas with highly varying and transitional climatic characteristics. There, water management and allocation schemes will need to be prepared for more severe droughts as well as more severe floods, which in addition will be less predictable. Agreements between countries in international basins will also need to account for that. Variability and uncertainty in the reliability of the resource call for flexible allocation schemes that are robust in times of surplus and deficit. While this need has been recognized, drought estimates implemented in past agreements likely did not consider enhanced effects due to climate change and hence the treaties are at risk to fail as they may have underestimated the potential severity of events. The long-term sustainability of hydropower-based energy generation and water allocation transboundary agreements within changing climate scenarios is currently being studied in a World Bank-Oregon State University funded project. However, more research is needed to finally develop better tools for water managers to include uncertain information of water availability and demand into integrated water management of international basins.

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