Conflict or cooperation? How does precipitation change affect transboundary hydropolitics?
Qifan Xia, Chaofeng Qian, Debin Du and Yang Zhang

ABSTRACT
Global climate change affects hydrology and ecology, and aggravates the contradiction between water resources supply and demand, thus leading to transboundary water conflict and cooperation attracting increasing attention. This paper uses the precipitation data sourced from the Global Precipitation Climatology Centre, hydropolitical data collected from the Transboundary Freshwater Disputes Database and, for approximately half a century of socioeconomic indicator for countries, to discuss the relationship between precipitation change and transboundary hydropolitics.
As demonstrated by the panel regression results, lower precipitation would lead to more water conflicts and more significant change of precipitation would lead to more water hydropolitical events. This result remains robust after adjustment being made to the defined thresholds of conflict and cooperation. The findings suggest that the countries in a transboundary river ought to avoid conflict and seek more cooperation, considering the uncertain prospect of precipitation changes.

Key words | climate change, hydropolitics, precipitation, transboundary

HIGHLIGHTS
- Changes in precipitation have been blamed for the increase in transboundary hydropolitics.
- We reviewed the literature on the relationship between precipitation changes and hydropolitics and proposed a hypothesis on the relationship of precipitation change and hydropolitics.
- Visualizing the distribution of water conflict and water cooperation, we seek to the relationship between precipitation change and hydropolitics.

INTRODUCTION
Human society is always accompanied by conflict in the competition for resources. When conflict turns violent, it can have significant consequences for the well-being of humans. Over the last decades, mortality resulting from war and interpersonal violence has reached 0.5–1 million deaths annually (Gleditsch et al. 2002; Mathers et al. 2008). Understanding the causes and solution of conflict has been a major project in the field of science.

Under the context of global environmental change, climate has received increasing recognition as a significant cause of human conflicts (Carleton & Hsiang 2016). As early as in the enlightenment period, Montesquieu started to give consideration to the relationship between climate and conflict, primarily from the perspective of climate influence on human character (Dell et al. 2012). In the most recent years, plenty of literature has started to issue warnings against diminishing resources and potential social conflicts arising from climate change, which has a real possibility to alter the supply of a resource and result in disputes over the allocation of it. In some cases, climatic conditions...
are possible that make people seek violence or cooperation to reach some pre-set goals.

The existing observations and climatological studies have demonstrated that one of the most noticeable impacts by climate change is manifested in the hydrological system (Bates et al. 2008). Water resources are definitely the primary resources closely associated with the survival of life and the sustainability of civilization. In the past, water gave birth to the civilization history of all countries across the world. Nevertheless, the unbalanced distribution of water resources caused conflicts on a frequent basis (Dimitrov 2002). For thousands of years, drought was viewed as a significant reason for nomadic tribes to attack farming country (Bai & Kung 2011). In a modern world, where water remains vitally important, transboundary watershed management has posed a challenge to all countries. Unbalanced allocation of water resources frequently causes water conflicts. Particularly after the Second World War, many new countries were founded due to decolonization, which fueled the national consciousness, but traditional boundaries have been changed so that the invisible danger of transboundary water conflicts increased rapidly.

A new term named ‘Transboundary hydropolitics’ is used to describe the political events related to water. Transboundary hydropolitics have been made the focal point of existing academic research, which is particularly significant at a time when global precipitation is changing. As revealed by the Fifth Assessment report of the Intergovernmental Panel on Climate Change (IPCC), the global average surface temperature (GMST) has risen since the late 19th century, and the period 1983–2012 is likely to be the warmest 30 years in the past 800 years (IPCC 2014a, 2014b). Global warming has contributed to a string of events either indirectly or directly, for instance, the changes in precipitation levels, temporal and spatial distribution, melting of mountain glaciers and rising sea levels. Moreover, climate can cause change in precipitation patterns, which in turn, can change runoff in many rivers. Meanwhile, climate change is likely to stimulate the demand for river water, as the more frequent occurrence of droughts puts more strain on alternative sources of water (Vijay et al. 2014). The resultant pressure on transboundary basins could increase international tension and heighten the risk of military conflicts. Therefore, climate change has attracted increasing attention in the field of water conflict.

Other creatures intensify intraspecific competition to adapt climate change (Best et al. 2007; Aitken et al. 2008), although the same is true of humans in some cases; human society is capable of making a response to crises in a cooperative way. The long-standing civilization created in human society, especially the establishment of the international order over the last century, has opened up the possibility for human beings to address the challenge as a community when encountering climate change (Petersen-Perlman et al. 2017). There is limited research conducted into collaboration as compared with the plentiful literature on climate and conflict. However, cooperation is definitely a possible and extensive solution to climate change. Therefore, the purpose of this paper is to achieve an empirical establishment of the causal path from precipitation change to transboundary hydropolitics and to investigate whether precipitation change could lead to more conflicts or cooperation. With over 2,000 national-year sample data based on 50 years of climate data and water events used as reference, this paper explores whether absolute and relative changes in precipitation have an effect on the probability of a country being involved in water conflict or water cooperation.

The remainder of this paper consists of four parts. The second section conducts the review and the hypothesis. Review of the existing literature and hypothesis are mainly about the relationship precipitation change and transboundary hydropolitics. The third section introduces the data and models in the research. The fourth section shows the empirical results. In the fifth section, the conclusion is drawn and discussed.

**REVIEW AND HYPOTHESES**

As mentioned in the Introduction, discussions about the association between climate and conflict have a long-standing history, and a fast-paced expansion of literature in this area has occurred over the past few years (Hsiang et al. 2011; Hsiang & Burke 2014; Burke et al. 2015). Climate, conflict and forced migration is widely discussed (Nordas & Gleditsch 2007; Abel et al. 2019).

In recent years, with the increasingly apparent changes in global precipitation and more extreme precipitation events, climate changes have also drawn a great deal of attention from water scholars (Bergholt & Päivi 2012). Climatic environments
have direct and widespread influence on the changes in water resources. For instance, the risk of persistent drought in the Euphrates–Tigris river basin has caused water shortage. Compounded by the impact of resource constraints, growing population, economic growth and diplomatic disputes between coastal countries, global climate change has contributed to persistent drought, which in turn, has exacerbated previous droughts, thus leading to various water conflicts (Caruso 2017). When water resources are in shortage and insufficient to satisfy the general demand, water conflicts arise (Oftadeh et al. 2016). The reasons of water conflicts include resource scarcity, transboundary management failure, competition for economic benefits, social and cultural conflicts, and political interests (Burgess et al. 2015; Bhnelt et al. 2014), but the effects of climate change are rarely defined.

Precipitation is a hot spot for climate change. There has been a long-standing debate among researchers working across different disciplines around the extent to which precipitation change is blamed for conflict, violence, or political volatility. A variety of different pathways associating climate with these outcomes has been suggested by Hsiang et al. (2013), where credible links are established between water resource and multilevel conflicts. The authors quantified the influence of climate on human conflict and found evidence linking climatic events to human conflict across a range of spatial and temporal scales and across all major regions of the world. Mehlum et al. (2006) considered precipitation as an instrumental variable for food price, which led to a discovery that more precipitation would have been effective in reducing violent and property crime in 19th century Germany. In addition, in modern Tanzania, Miguel (2005) and Edward et al. (2004) gathered evidence on the role played by extreme precipitation change in violent crime. It is inevitable for interpersonal conflict to result in social tension, group conflict, and even war. This has prompted many researchers to pay attention to whether the changes in precipitation have the possibility of influencing intergroup relationships. As discovered by Bai & Kung (2011), less rainfall is associated with frequent Sino-nomadic conflicts in Chinese history. They found nomadic incursions into settled Han Chinese regions to be positively correlated with less rainfall and negatively correlated with more rainfall. As well, Haug et al. (2005) suggested a century-scale decline in rainfall put a general strain on resources contributing to the social stresses that led to the Maya demise. Hendrix & Salehyan (2012) demonstrated that greater rainfall deviation would result in causing more civil conflicts, and that environmental shocks have a close relationship with unrest.

The correlation between precipitation change and water conflicts shows ambiguity. Some evidence suggests that climate factors are only weakly associated with water conflicts and such a correlation is largely reliant on socioeconomic conditions (Wolf et al. 2003a, 2003b). Nevertheless, some of the prior hydropolitics studies have revealed that water shortage is beneficial to the formulation of transboundary river treaties (Tir & Ackerman 2009). There is also evidence suggesting that the reduction of precipitation could prompt water cooperation among countries (Dinar et al. 2010, 2015). In fact, the impact of climate change on precipitation can also be a driving force for water cooperation in human societies. For example, Salehyan & Hendrix (2014) argued that water scarcity might have a pacifying effect on armed conflict. Lautenberger & Norris (2016) discussed the initiative to designate international water law (IWL) to be discussed in the context of climate change. Hemati & Abrishamchi (2020) demonstrated that an integrated, sustainable and efficient water allocation considering changes in water resources due to climate change and change of users’ demands is necessary. Fostering cooperation and managing conflict thus become fundamental in transboundary water management (Mgquba & Majodzi 2020). As well, a new study performed by Dinar et al. (2019) indicates that a low variability of precipitation is conducive to enhancing hydropolitical relationship between different countries.

Overall, the issue of water conflict caused by climate change has been covered in the existing literature, but the relationship between precipitation and hydropolitics, including water conflict and water cooperation, has rarely been clearly quantitatively demonstrated. On the one hand, the decrease of precipitation may lead to more water conflicts, which is recognized by most researchers (Haug et al. 2005; Bai & Kung 2011; Oftadeh et al. 2016; Caruso 2017), but some opinions are different (Tir & Ackerman 2009; Salehyan & Hendrix 2014), thus we continue the approach to demonstrate which is more common and credible. On the other hand, a few scholars have explored the amount of precipitation (absolute change) on water events (Mehlum et al. 2006; Hsiang & Burke 2014), but frequent fluctuations in precipitation (relative change) are rarely considered. We can imagine that the
frequent fluctuations in precipitation certainly promote frequent changes in the natural and social environment of a basin (Dinar et al. 2019), and may cause more water events. Therefore, we seek to elaborate the relationship existing between precipitation and transboundary hydropolitics, and how precipitation change is examined, involving the absolute amount of precipitation and the annual relative anomaly of precipitation that have effects on international water conflicts and water cooperation. Based on the summary of the scattered achievement in the existing literature and objectives set for this research, the following hypotheses are raised for empirical study.

**Hypothesis 1a:** There is a certain relationship between absolute change in precipitation and hydropolitics: less precipitation can result in more cooperation.

**Hypothesis 1b:** There is a certain relationship between absolute change in precipitation and hydropolitics: less precipitation can result in more cooperation.

‘Absolute change in precipitation is to present absolute change of annual precipitation, referring to the absolute amount of precipitation’.

**Hypothesis 2:** There is a certain relationship between relative change in precipitation and hydropolitics: more frequent changes in precipitation can increase hydropolitical events.

‘Relative change in precipitation refers to the relative variability of annual precipitation, the absolute value of the difference between the actual precipitation and the multi-year average precipitation, reflecting the stability and frequency of precipitation’

**DATA AND METHODS**

**Climate data**

The research focuses on the discussion of global climate change and human society on rainfall and hydropolitics. The precipitation dataset is collected from GPCC (Global Precipitation Climatology Centre) (Ziese 2011), with the latest version of ‘Total Full V2018 (0.5 × 0.5)’, gathered from about 67,200 stations around the world that feature a record duration of over one decade (Schneider et al. 2017).

This dataset provides monthly precipitation statistics from 1891 to 2016 covering the whole globe with 0.5° latitude × 0.5° longitude resolution. Some other relevant studies also cite these data in different versions (Sun et al. 2018).

Considering that the size of some countries is excessively small, with Python scripts and ArcGIS software 10.2, each 0.5° × 0.5° grid is distributed to its country with a 30 km window. Subsequently, annual precipitation of each grid is calculated, and the annual precipitation (the mean of grids’ annual precipitation) is aggregated at the country level.

Due to the large time span and the large gap between the data, we standardized the data in order to eliminate the influence of dimension and the variation of the variable itself and the value size between different data. The annual precipitation data recorded as LNPrec is processed with logarithmic transformation by the natural logarithm. LNPrec presents absolute change of annual precipitation. The relative variability of annual precipitation (RVPrec) refers to the ratio of average deviation of precipitation (the absolute value of the difference between the actual precipitation and the multi-year average precipitation) to multi-year average precipitation over the years 1948–2008), which is significant to assess the stability of precipitation (Gregory 1995; Xiao et al. 2018). Finally, there is a national annual precipitation dataset included for this research. Due to the limits of hydropolitics dataset and some socioeconomic variables, this paper has to primarily use the precipitation data collected from 1960 to 2008.

**Conflict and cooperation data**

The hydropolitics dataset is sourced from the Transboundary Freshwater Disputes Database (TFDD). This dataset is from Oregon State University and consists of over 6,400 water-related political events occurring between countries that share a river basin for the period around the globe between 1948 and 2008 (Transboundary Freshwater Dispute Database 2018). The TFDD dataset has been taken as the basic data for many transboundary water studies (Munia et al. 2016; Stefano et al. 2017; Dinar et al. 2019).

The field ‘BAR_SCALE’ in the TFDD dataset presents information on whether an event is regarded as a conflict or a cooperation quantitatively. Scores in the field range from −7 to +7, with −7 indicating the most negative events.
(the highest level of conflicts, war). For instance, 0 denotes neutral events and +7 signifies the most positive events (two countries merge to one country voluntarily and peacefully). The threshold in our research design is ±3. Being equal to or more than +3 indicates that there is a material agreement or support, which is viewed as a cooperation. On the contrary, being equal to or less than −3 suggests that there is a material hostile action, which is treated as a conflict. Event scores from −2 to +2 are merely verbal-level issues, as shown in Supplementary Material, Table A1.

Based on the threshold set, two outcome variables are identified as the number of conflict events or cooperation events a country is implicated in for a specific year. As well, concerning robust tests, some researcher have tried to modify the threshold. For more details about the TFDD dataset and the scores we can refer to Yoffe (2002).

Socioeconomic and other data

With climate factors being excluded, the issue of water source availability is closely related to the constant-rising demand driven by population, agriculture, and economics (Falkenmark 1986; Wheida & Verhoeven 2007; Gu et al. 2012). Therefore, there are a number of socioeconomic variables subject to control in the research model. Also, population factors such as total population, annual population growth rate, and density of population need to be controlled. Various socioeconomic variables, including area of agricultural land, proportion of agricultural land in all national land for controlling agriculture factors, GDP, growth rate, per capita GDP, and life expectancy at birth, are sourced from World Development Indictors (WDI) and the Food and Agriculture Organization of the United Nations (FAO 2018). The WDI database represents a collection of development indicators gathered from officially recognized international sources, and these are the latest and most accurate global development data. Records of the WDI database can be traced back to 1960. To maintain the consistency of the panel data, the socioeconomic and other variables of this paper are collected from 1960 to 2008.

In addition, water conflicts are affected by military and political factors. Therefore, the proportion of military expenditure in GDP of a country is also seen as a control variable, which is available from the WDI database as well. According to Dinar et al. (2019), and following the democratic peace theory (Lemke & Reed 1996; Mesquita et al. 1999), scholars and scientists have considered that political regime type has an impact on international conflict and cooperation (Brochmann & Hensel 2009; Tir & Stinnett 2012). It is proposed that a combined democracy score variable should be added to the model for control of this factor. With different ideology and national institutions (former) Socialist countries exhibit unique patterns and characteristics in the international community (Morgenthau 1985; Lundestad 2014), which prompts the use of a dummy variable to verify whether a country is a (former) socialist country. Finally, during the Cold War and for the subsequent few decades, a significant event that has changed the international environment occurs every ten years, for which a dummy variable for each decade is fixed as well. The data on military and political variables cover the period of 1960–2008 as well. Table 1 indicates the descriptive statistics of these variables.

Model design

The main challenge for the regression is to ensure that variables are relevant and valid (Murray 2006). Rather than presuming that all confounders are accounted for in a cross-sectional regression, the bulk of recent studies estimate the effect of climate on conflict by using time series variation for identification, usually in a panel data context (Burke et al. 2015). In our research design, we subdivided the explanatory variable, namely, precipitation index, into absolute change and relative change. However, according to the existing literature, hydropolitics is quite complicated. The first problem is how to quantify the explanatory variable of this paper, that is, hydropolitics (including water conflict and water cooperation); we use the classification standard of Oregon State University to divide hydropolitics into water cooperation and water conflict by setting a threshold. In addition, due to the complex background of hydropolitics, economic, agricultural, political, military and other factors may lead to water conflicts and water cooperation. Therefore, in order to achieve the goal of this paper, the above non-climatic factors must be controlled.

According to econometric theory, panel data model estimation has two effects, fixed effect (FE) model and random effect (RE) model, generally using the Hausman test for determination. The Hausmann test is to compare the coefficient difference between the FE model and RE model; if the
Original hypothesis is accepted, i.e., the significance level $p \geq 0.05$, the random effect model should be selected; otherwise, $p < 0.05$, that is, reject the original hypothesis and choose the FE model. In general, the time fixed effect is controlled and has to undergo several robustness tests. The question in the individual fixed effect, in this study, is whether the factors that change with each country need to be controlled. After the Hausmann test, $p$ values are far greater than 0.05, so we choose fixed effect and the individual fixed effect is not controlled.

Then, to ensure the accuracy and credibility of the estimated results, we continue through the F test finding that the FE model is significantly better than mixed regression. Further, by comparing the effects of the first-order difference estimator method and the within-group estimator method, it is determined to use the within-group time estimator FE panel model for regression analysis. Through the above analysis and drawing on the relevant literature (Burke et al. 2015), the regression model of the relation between precipitation change and hydropolitics is estimated as follows:

$$
C_{onf,i,t} = \beta_0 + \beta_1 \text{Prec} + \beta_2 X_{i,t} + \beta_3 Y_t + \varepsilon_1 \tag{1}
$$

$$
C_{oop,i,t} = \beta_4 + \beta_5 \text{Prec} + \beta_6 X_{i,t} + \beta_7 Y_t + \varepsilon_2 \tag{2}
$$

where countries are indicated by $i$, observed year is denoted as $t$, $\beta$ is the parameter of regression (especially, $\beta_0$ is the constant), and $\varepsilon$ represents the error. $C_{onf,i}$ or $C_{oop,i}$ refers to the count of conflicts or cooperation of country $i$ in year $t$. Prec denotes the variables of precipitation (LNPrec or RVPrec in terms of absolute change and relative change) of country $i$ in year $t$. $X$ stands for a vector of different group of controlled variables described above (population, agriculture, economic development, military and politics). $Y$ denotes the decade dummy for year $t$.

This modern panel data approach is introduced and applied in various conflict literature by numerous researchers (Edward et al. 2004; Bai & Kung 2017; Kim 2016). In this model, $C_{onf}$ or $C_{oop}$ represents a dependent variable, and Prec indicates the core explanatory variable. The key is to estimate the influence exerted by precipitation change on the number of conflicts or cooperation with positive or negative value, and the significance attached to regression coefficient $\beta_1$. All of the data used for regression are from 1960 to 2008.

To make the estimation results more robust, hierarchical regression analysis is adopted. First, add various variables continuously, and finally add all variables. Each column from Tables 2–6 is used to represent the regression results when
different variables are added. ‘Yes’ means that this variable has been added. ‘No’ means that this variable is not added.

RESULTS

Descriptive statistics and evidence

In order to verify the hypothesis that precipitation changes will affect hydropolitics, on the basis of maintaining data integrity and reliability, we constructed the above-mentioned national panel data for almost half a century from 1960 to 2008. Table 1 indicates the descriptive statistics of each variable. Then, multi-year (1960–2008) average of annual precipitation, frequency of conflicts or cooperation, and spatial visualization is calculated using ArcGIS, as shown in Figures 1 and 2. Darker shading denotes more precipitation in this country, and larger size of a circle indicates a higher frequency of hydropolitics events (conflict or cooperation) in this country.

As shown in Figures 1 and 2, water conflicts tend to arise in arid areas surrounding the Tropic of Cancer. There is an

---

Table 2 | Regression results of LNPre on water conflict (Conf3)

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>lnpre</td>
<td>– 0.0560</td>
<td>– 0.0614</td>
<td>– 0.0546</td>
<td>– 0.0566</td>
<td>– 0.0541</td>
<td>– 0.0386</td>
</tr>
<tr>
<td>(0.963)</td>
<td>(0.768)</td>
<td>(0.499)</td>
<td>(0.916)</td>
<td>(0.889)</td>
<td>(0.779)</td>
<td></td>
</tr>
<tr>
<td>Military and politics</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Population</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Economic development</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Agriculture</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Decade fixed effect</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>_cons</td>
<td>0.483***</td>
<td>0.368***</td>
<td>– 0.0458</td>
<td>0.489***</td>
<td>– 0.263</td>
<td>– 0.236</td>
</tr>
<tr>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
</tr>
<tr>
<td>N</td>
<td>2,358</td>
<td>1,021</td>
<td>2,006</td>
<td>2,247</td>
<td>901</td>
<td>901</td>
</tr>
</tbody>
</table>

Note: The p value is in parenthesis (the same as below).
* p < 0.1, ** p < 0.05, *** p < 0.01.

Table 3 | Regression results of LNPre on water cooperation (Coop3)

<table>
<thead>
<tr>
<th>Variables</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>lnpre</td>
<td>– 0.00279</td>
<td>0.0312</td>
<td>– 0.0489</td>
<td>– 0.00693</td>
<td>– 0.015</td>
<td>– 0.0316</td>
</tr>
<tr>
<td>(0.963)</td>
<td>(0.768)</td>
<td>(0.499)</td>
<td>(0.916)</td>
<td>(0.889)</td>
<td>(0.779)</td>
<td></td>
</tr>
<tr>
<td>Military and politics</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Population</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Economic development</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Agriculture</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Decade fixed effect</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>_cons</td>
<td>1.637***</td>
<td>1.782**</td>
<td>3.684***</td>
<td>1.523***</td>
<td>2.241*</td>
<td>1.536</td>
</tr>
<tr>
<td>(0.822)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.001)</td>
<td>(0.019)</td>
<td>(0.019)</td>
</tr>
<tr>
<td>N</td>
<td>2,358</td>
<td>1,021</td>
<td>2,006</td>
<td>2,247</td>
<td>901</td>
<td>901</td>
</tr>
</tbody>
</table>

Note: The p value is in parenthesis (the same as below).
* p < 0.1, ** p < 0.05, *** p < 0.01.
apparent distribution pattern in Figure 1 that lower precipitation is accompanied by more conflict events. Beyond direct visual findings, statistical evidence suggests this sort of space-coupling phenomenon. Using data from 1948 to 2008, it shows that the Pearson correlation coefficient between precipitation and conflict was −0.13, which was significant at the 0.001 level. It demonstrates that annual precipitation has a significant negative association with how frequently conflicts arise. In Figure 2, nevertheless, the pattern is more confusing and the distribution of precipitation and cooperation events seems to be randomized.

Baseline results

To strictly and reliably determine further the causality, we carried out systematic regression analysis on the previously introduced research model. The panel data regression model not only improves the degree of freedom through a combination of observations made in different countries in different years, but also reduces the collinearity of explanatory variables. In the estimation of linear regression models, mean VIF (variance inflation factor) is 1.84, significantly lower than the threshold of the multicollinearity. The panel model also avoids individual heterogeneity problems, to a certain extent. Meanwhile, the corresponding time fixed effects are to be controlled by setting the decade dummy variables. In order to address the potential heteroscedasticity and autocorrelation problems arising from the panel data, we take the robust option to estimate the heteroscedastic robust standard error in Stata 14 (a multi-function statistical software).

To validate the robustness of the regression results, a different group of control variables is added in every estimation, and the final estimation of all control variables is in the last column. In addition, taking the size of the article and clarity tables into consideration, regression coefficients and p values of control variables are hidden when some significant findings are referred. Baseline results of the conflict

<table>
<thead>
<tr>
<th>Table 4</th>
<th>Regression results of RvPrec on hydropolitical events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables</td>
<td>1 Coop3</td>
</tr>
<tr>
<td>Rvprec</td>
<td>1.319*</td>
</tr>
<tr>
<td>(0.095)</td>
<td>(0.009)</td>
</tr>
<tr>
<td>Military and politics</td>
<td>Yes</td>
</tr>
<tr>
<td>Population</td>
<td>No</td>
</tr>
<tr>
<td>Economic development</td>
<td>No</td>
</tr>
<tr>
<td>Agriculture</td>
<td>No</td>
</tr>
<tr>
<td>Decade fixed effect</td>
<td>No</td>
</tr>
<tr>
<td>_cons</td>
<td>1.828***</td>
</tr>
<tr>
<td>(0.001)</td>
<td>(0.007)</td>
</tr>
<tr>
<td>N</td>
<td>1,021</td>
</tr>
</tbody>
</table>

Note: The p value is in parenthesis (the same as below).
* p < 0.1, ** p < 0.05, *** p < 0.01.

<table>
<thead>
<tr>
<th>Table 5</th>
<th>Results of robust test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variables</td>
<td>1 Conf1</td>
</tr>
<tr>
<td>LnPrec</td>
<td>−0.0956</td>
</tr>
<tr>
<td>(0.673)</td>
<td>(0.942)</td>
</tr>
<tr>
<td>Rvprec</td>
<td>1.965*</td>
</tr>
<tr>
<td>(0.076)</td>
<td>(0.033)</td>
</tr>
<tr>
<td>Military and politics</td>
<td>Yes</td>
</tr>
<tr>
<td>Population</td>
<td>Yes</td>
</tr>
<tr>
<td>Economic development</td>
<td>Yes</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Yes</td>
</tr>
<tr>
<td>Decade fixed effect</td>
<td>Yes</td>
</tr>
<tr>
<td>_cons</td>
<td>−0.611</td>
</tr>
<tr>
<td>(0.647)</td>
<td>(0.153)</td>
</tr>
<tr>
<td>N</td>
<td>901</td>
</tr>
</tbody>
</table>

Note: The p value is in parenthesis (the same as below).
* p < 0.1, ** p < 0.05, *** p < 0.01.
model are indicated in Table 2, where dependent variable is denoted as Conf3.

Tables 2 and 3 present baseline results from the regressions where the dependent variable is either Conf3 or Coop3. There are six sets of regressions for each, along with different columns controlling various groups of control variables. Column 1 controls nothing, with military and political factors being controlled in column 2, population and economic development factors being controlled in column 3, and agriculture factors being controlled in column 4. As well, column 5 controls all the factors in columns 1–4. Finally, all control variables and decade fixed effect are hereby added in column 6.

As shown in Table 2, under different control variables, the coefficients of LNPrec are significantly negative at all times, mostly at \( p < 0.001 \) level, suggesting that less precipitation tends to trigger more conflict hydropolitical events for a country. Therefore, Hypothesis 1a is supported by empirical results.

According to column 6, which contains all control variables, one standard deviation reduction of LNPrec will increase conflict by an extra 0.39 times, which is about

---

**Table 6 | Results of hysteresis effect analysis**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Conf3</th>
<th>Conf3</th>
<th>Coop3</th>
<th>Coop3</th>
<th>Conf3</th>
<th>Conf3</th>
<th>Coop3</th>
<th>Coop3</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.In prep</td>
<td>0.001</td>
<td>0.086</td>
<td>0.042</td>
<td>0.086</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.987)</td>
<td>(0.565)</td>
<td>(0.732)</td>
<td>(0.794)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.Rvprec</td>
<td></td>
<td>-0.100</td>
<td>-0.328</td>
<td>0.606</td>
<td>2.019</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.460)</td>
<td>(0.743)</td>
<td>(0.351)</td>
<td>(0.329)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Military and politics</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Population</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Economic development</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Decade fixed effect</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>_cons</td>
<td>-0.595</td>
<td>-1.664</td>
<td>0.501</td>
<td>1.135</td>
<td>-0.593</td>
<td>-1.102</td>
<td>0.784</td>
<td>1.725</td>
</tr>
<tr>
<td></td>
<td>(0.182)</td>
<td>(0.219)</td>
<td>(0.686)</td>
<td>(0.606)</td>
<td>(0.06)</td>
<td>(0.455)</td>
<td>(0.537)</td>
<td>(0.507)</td>
</tr>
<tr>
<td>N</td>
<td>652</td>
<td>652</td>
<td>652</td>
<td>652</td>
<td>652</td>
<td>652</td>
<td>652</td>
<td>652</td>
</tr>
</tbody>
</table>

Note: L. means the variable is first-order lagged. The p value is in parentheses (the same as below).

* \( p < 0.1 \), ** \( p < 0.05 \), *** \( p < 0.01 \).
86.7% of one standard deviation of Conf3. In general, the results shown in Table 2 confirm that the precipitation has a negative effect on hydropolitical events. In respect of those control variables, there are some appealing findings as well. In all scenarios, life expectation and military ratio both strengthen a negative effect on hydropolitical events on conflict events. It suggests that if a country has a higher ratio of military expedition and longer life expectation (an extremely important index for development), it would be involved in more water conflicts.

As revealed in Table 3, the coefficients of LNPrec are invariably negative but insignificant. It is thus insufficient to suggest that precipitation has exerted influence on the transboundary water cooperation. **Therefore, Hypothesis 1b is not held by empirical results.**

Then, rooted in Chinese classical political wisdom, the effects of relative changes of precipitation on transboundary hydropolitics are investigated in this paper, under the insights of Hendrix & Salehyan (2012). In Table 4, RVPrec replaces LNPrec as the independent variable, and other controlled sets are the same as in Tables 2 and 3.

Table 4 presents the regression results of RVPrec on Coop3 and Conf3. RVPrec represents a major determinant of Coop3 across countries. The significance in columns 2 and 3 is at $p < 0.01$ level and the coefficients are positive, implying that more extreme deviations in rainfall will prompt more cooperation. As shown in column 3, one standard deviation increase in RVPrec from the mean value is related to a quarterly increase of cooperation in the year. The estimation of control variables are excluded from Table 4, but there is more information worth reporting. Former socialist countries remain positive and significant at $p < 0.05$ level, suggesting that they have a tendency to have more cooperation than other countries. Moreover, the agriculture ratio produces a significant positive effect on cooperation. A higher agricultural land use ratio is more likely for a country to reach more water cooperation. In contrast, the efficiency of military ratio turns out to be significantly negative, indicating that transboundary water cooperation is even less likely to be reached in military-focused countries. For Conf3, the estimated coefficients are positive and significant, especially in columns 6 and 7, which both contain a majority of the control variables, indicating that more extreme deviations in rainfall will result in more conflicts. **Therefore, Hypothesis 2 is initially verified.**

In general, a RVPrec increase of one standard deviation from the mean value is associated with a 28.9% increase of conflicts in the year. Military ratio and life expectation are also significant factors that cause conflicts, the effects of which show similarity to the results shown in Table 2.

**Robust test**

In studies of causal inference, the main consideration is given to the endogeneity. In this research, on the one hand, panel data are competent to mitigate the issue of missing variables, to some extent. On the other hand, the
association between precipitation and human factors is complicated and difficult to completely understand at present (Schaller et al. 2016). According to the IPCC AR5 report (IPCC 2014a, 2014b), human activities are speculated to have an effect on precipitation change in the second half of the 20th century. However, the corresponding direct impact relationship remains unclear, and the lack of clarity remains apparent (Hegerl et al. 2010; IPCC 2014a, 2014b). Therefore, the model also seeks to remove the mutual causal concerns over the core explanatory variables and the dependent variables.

As well, a number of robustness tests have been conducted on this model. Defining the conflict or cooperation threshold (‘BAR_SCALE’ score) is of great significance to this research, which provides the basis for building core explanatory variables. In robustness tests, we seek to revise the threshold from ±3 to ±1, as shown in Supplementary Material, Table A1, which is no different to extending the definition of conflict or cooperative event to the verbal representative actions.

Following the change in the threshold to ±1, the regression results are shown in Table 5. In columns 1 and 2, the effects of LN_Prec on Conf1 and Coop1 are estimated, and in columns 3 and 4, effects of RV_Prec on Conf1 and Coop1 are estimated. In any column of Table 5, all control variables of our research design are included to control similarly to column 6 of Table 2.

As indicated in Table 5, effects of LN_Prec on Conf1 and Coop1 are insignificant. The results show that the mild hydropolitics of verbal representative actions has little relationship with the change of absolute precipitation. On the contrary, the coefficients of RV_Prec in columns 3 and 4 are both positive and significant, which indicates that for more general water conflict or cooperation, RV_Prec remains representative of a major determinant. It is highlighted that the relative change in precipitation plays a vital role in transboundary hydropolitics as compared to the absolute change. 

Therefore, Hypothesis 2 is verified.

**Hysteresis effect**

The results of the general model with no lag contradict the null hypothesis that absolute or relative changes in precipitation are not impacting on water conflicts between countries. Many scholars have supposed that climate factors have hysteresis effects on human society (Dell et al. 2012; Auffhammer et al. 2015). Under various circumstances, regression models also affect the lagged climate variable (Burke et al. 2015). Considering that hysteresis effects will likely paint a more complete picture of the climate/conflict relationship than estimating Equations (1) or (2) alone, first-order lag variables (one year lagged) are taken as the replacement for the original core explanatory variables.

Regression results with lagged independent variable are indicated in Table 6. Columns 1–4 represent the association between LN_Prec of one year lagged and hydropolitics, conflict or cooperation. Columns 5–8 show the independent changes to be lagged for RV_Prec. Likewise, all control variables are contained in any column as in column 6 of Table 6. As indicated in Table 6, no hysteresis effect exists in our models, even if the independent variable and dependent variable are changed in various settings. Meanwhile, if the threshold changed to ±5, the conclusion still stands if it only takes the direct-armed conflicts or cooperation of substantial strategic significance into consideration. Our hypothesis is fully demonstrated.

**CONCLUSION AND DISCUSSION**

Global climate change is becoming more and more obvious, which leads to increasing attention of hydropolitics. On the one hand, the most direct water problem caused by climate change is drought or water scarcity. On the other hand, water cooperation can effectively address the problem of water shortage by coordinating the allocation of water resources. Therefore, water conflict and water cooperation have become key topics in hydropolitics research. Precipitation as the cause of water conflict and the driving force of water cooperation has been discussed by society, but the specific relationship between precipitation and these water political events has not been clearly concluded. Therefore, this article attempts to clarify the relationship between precipitation and hydropolitics.

This paper contributes to the existing literature in two ways. First, rooted in classical Chinese political wisdom of Confucius about ‘interaction between heaven and man’, we make an argument that precipitation change should be categorized into absolute precipitation and relative precipitation.
Under this political philosophy hypothesis, this paper pictures a naive correlation between precipitation and politics, which has been extensively debated in recent years, but still with no clear conclusion. Second, unlike previous studies that used precipitation changes as control variables, this paper uses precipitation changes as the core variable to try to test the impact of precipitation changes on cross-border water political events. Our combination of about half a century of climate and hydropolitical data collected from 1960 to 2008, and controlling other significant variables, discovered that precipitation change exerts a substantial influence on transboundary hydropolitics, so that two hypotheses are validated. To be specific, from the absolute changes of precipitation, the drier areas with reduced precipitation are more likely to have transboundary water conflicts, which is basically consistent with the studies of Caruso (2017) and Oftadeh et al. (2016).

From the relative changes of precipitation, water conflicts will also change as relative precipitation changes, similar to Hendrix & Salehyan (2022) findings that precipitation discrepancies worsen internal water conflicts. The same is true of the transboundary water conflicts in this paper. Fortunately, it can prompt more cooperation as well. Even if the definition interval of water conflict and cooperation is adjusted, our conclusion is still valid. This further confirmed Dinar et al.’s (2015, 2019) findings. In addition, for the transboundary hydropolitics, although the relative change of precipitation will be more frequent, our results have found that the lag effect of climate change is not obvious.

As stated by Confucius, balance is more important than quantity. A country’s position on Earth determines its absolute amount of precipitation and it is unlikely to change. Therefore, the fluctuation of precipitation, which is heavily impacted by climate change, becomes more important. More extreme precipitation can result in more conflicts, but more cooperation may also be carried out under the balancing values.

Some limitations should be taken into account in future studies. First, the existing study still does not reach a highly credible conclusion as to global precipitation change pattern. Although we try to discuss the relationship between precipitation and transboundary hydropolitics from a new perspective, transboundary hydropolitics is a complex system coupled with nature and humanity. Simply exploring the correlation maybe overlooks the complex background of hydropolitics. Second, there are still some deficiencies in our model, such as not exploring transboundary hydropolitics under different scenarios in different drainage basins, and the results still need more verification.

Overall, we believe that this study will provoke more interest in the relationship between climate change and hydropolitics. As the IPCC warns, human demand for water is growing, and water usage has been on the increase worldwide by about 1% annually since the 1980s. However, the amount of freshwater placed at the disposal of everyone around the world has been in decline. Water scarcity continues to deteriorate and water conflicts are manifested in various forms due to population growth, exacerbated water pollution, lack of planning and management of transboundary and other shared water, and inefficiency in water supply and distribution systems (Dinar et al. 2015; Carleton & Hsiang 2016). Encountering uncertain climate change prospects, countries ought to pay more attention to water cooperation and take the proper approach to resolve disputes among themselves and prevent conflicts from escalation. The key to sustainable development lies in the establishment of fair and effective water resources allocation mechanisms through cooperation in various forms.

ACKNOWLEDGEMENTS

The study was funded by the Chinese Academy of Sciences Strategic Pilot Research Program Category A (XDA20100311) and National Natural Science Foundation of China (No. 41471108). The authors acknowledge Global Precipitation Climatology Centre and Oregon State University for the Transboundary Freshwater Disputes Data and climate data.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories (https://climatedataguide.ucar.edu/climate-data/gpcc-global-precipitation-climatology-centre) Global Precipitation Climatology Centre (https://transboundarywaters.science.oregonstate.edu/content/transboundary-freshwater-dispute-database) Oregon State University for the Transboundary Freshwater Disputes Data (https://databank.worldbank.org/source/world-development-indicators) World Development Indicators (http://www.fao.org/land-water/databases-
The Food and Agriculture Organization of the United Nations.

REFERENCES


Yolle, S. 2002 Basins at Risk: Conflict and Cooperation Over International Freshwater Resources. PhD Dissertation, Department of Geosciences, Oregon State University, Corvallis, OR, USA.


First received 11 August 2020; accepted in revised form 1 December 2020. Available online 22 January 2021