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Desalination and Transboundary Water Conflict and Cooperation: A Mixed-Method Empirical Approach

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Abstract: The impact of the adoption of desalination on relations between parties in transboundary settings is unclear. The previous literature has indicated that the effect of desalination on conflict and cooperation is an empirical matter. By reducing scarcity and variability, the adoption of desalination is likely to reduce the potential for conflict, though it may also create new conflicts, for instance, over water of marginal quality or over issues of equity. Its effect on cooperation is even more ambiguous, as it both offers parties more flexibility, which is likely to increase cooperation, but can be implemented unilaterally, which may reduce the need for cooperation. The little empirical work that has been published investigating these impacts has been largely based on anecdotal evidence or individual case studies. This paper presents a more systematic look at these impacts, using a mixed-method (quantitative and qualitative) analysis of interstate interactions before and after the adoption of large-scale seawater desalination. The results support the contention that while desalination has the potential to reduce conflict and increase cooperation, the impact of desalination on hydropolitics cannot be assumed a priori. Rather, it is largely context-dependent, and as such, it should not be viewed as a technological fix for transboundary water relations.

Keywords: conflict; cooperation; desalination; hydropolitics; transboundary waters; water securitization

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1. Introduction

Over 20,000 desalination plants are currently operating in over 150 countries [1]. Countries are increasingly adopting desalination as a strategy for dealing with water scarcity and water quality issues, especially in the face of population growth, economic growth and climate change [2]. The United Nation's estimates that water demand is expected to increase by up to one-third by 2050 [3], and desalination will play an increasing role in meeting this demand, especially as per-unit costs decrease. According to the International Energy Agency [4], desalination capacity will increase by up to 13-fold from its levels in 2014. While much of the current desalination capacity is located in economically developed countries, desalination is increasingly being adopted in developing economies as well (e.g., [5–7]).

As desalination plays an increasingly important role in national water supplies, it is also likely to affect water policy in transboundary basins. A limited amount of previous work has demonstrated the actual and potential effects of desalination on transboundary relations. Some observers have commented on the potential for desalination to change upstream–downstream power dynamics (e.g., [8–10]). Aviram et al. [10] also posited that, by reducing both scarcity and variability, both factors potentially leading to conflict between parties, desalination should reduce interstate disputes. However, because the adoption of desalination both creates options for cooperative agreements but also allows for countries to act unilaterally, its impact on cooperation between parties cannot be predicted a priori. Some speculate that desalination could actually lead to new forms of conflicts, especially over the impacts of the process (e.g., [11]). Katz provides examples of how desalination has actually led to new conflicts by, for instance, introducing new water sources (e.g., seawater and brackish sources) into the calculus of transboundary management [12]. Such findings imply that neither desalination's impact on conflict nor cooperation can be assumed a priori.

While the implications of the work just cited are that the impact of desalination on both international conflict and cooperation are empirical matters, the bulk of work addressing this is either anecdotal or based on case studies. To our knowledge, no quantitative approach has been adopted to evaluate these impacts. This study is a first attempt to address this gap in the literature. We present both a quantitative and qualitative assessment of desalination's impacts on conflict and cooperation in multiple transboundary settings. The results of the work support the contention that while desalination has the potential to reduce conflict and increase cooperation, the actual impact of desalination on hydropolitics is largely context-dependent, and as such, it should not be viewed as a technological fix for transboundary water relations.

The study proceeds as follows: Section 2 provides a very brief overview of some of the literature on transboundary hydropolitics, with an emphasis on the role of desalination. Section 3 lays out the specific research questions asked and the methods employed in this analysis. Section 4 presents the results, first of a statistical analysis and then of a comparative qualitative rubric. Section 5 presents a discussion of the policy implications of the findings and conclusions.

2. Conflict and Cooperation over Transboundary Waters and the Role of Desalination

The possibility of conflict over shared waters has gained much attention in both the popular press (e.g., [13]) and the academic literature (for reviews of some of the literature, see [8,14]). Empirical studies have found that instances of large-scale violent conflict over shared waters is relatively rare and far less than instances of cooperation over shared waters (e.g., [15]). Still, past observations are not necessarily indicative of the future, especially as scarcity affects an increasing number of populations [16]. Instances of low-level conflict over shared waters are still common and seem to be increasing [17].

Many quantitative empirical studies of water conflict and cooperation have used the Basins-At-Risk (BAR) scale Transboundary Freshwater Dispute Database (TFDD) [18], which categorizes instances of water conflict and cooperation on a sliding scale from -7 to 7, with negative numbers representing increasing degrees of conflict and positive numbers increasing degrees of cooperation (e.g., [15,19–21]). Others have used similar databases [22,23]. Though popular, such databases have come under some critique. In addition to questions over the scope of the coverage of the databases, which are skewed towards English language and European language news sources, some have noted that conflict and cooperation are not necessarily opposite ends of a continuous spectrum and that they can coexist in the same relationship [24,25]. Acknowledging this, some empirical studies have evaluated the impact on conflict and cooperation separately as well as in the aggregate [26,27]. Other critiques include that some forms of cooperation may, in fact, be imposed by hegemonic powers rather than being indicative of willing collaboration [24,28].

Many studies on hydropolitical relations have adopted qualitative approaches. One such approach that has been utilized in a number of works is the Transboundary Waters Interaction NexuS (TWINS) framework, first proposed by Mirumachi (2007). The original version analyzed interactions by positioning them on a two-dimensional matrix instead of placing them on a continuum with two opposite ends. Mirumachi [29,30] developed this instrument based on Craig's work [31]. The author acknowledged that different levels formed cooperation and conflict processes, which Craig defined on a 2×2 cells matrix. Mirumachi expanded this matrix to a more detailed one and adapted it to hydropolitics and security theory by incorporating the conflict and cooperation scales. As Zeitoun and Mirumachi put it, "the selection of scales on both axes of TWINS also allows the political faces of the interaction to emerge, with the explicit recognition that particular faces of cooperation have neutral or less desirable features along with the positive ones" [24]. Under such a scheme, analysts can observe interactions over water relations between riparian actors without limiting them to being categorized as strictly conflictual or cooperative. Rather, "the political context determining different combinations of conflictive and cooperation interactions become a very important analytical focal point" [24].

In the model, as shown in Figure 1 the first axis represents the different intensities of conflictual interactions, going from low conflictual intensity to violent interactions [29]. The different categories in increasing levels of conflict in Mirumachi's scale are: non-politicized, politicized, securitized/opportunitized, and violized. Cooperative interactions are located on a second axis. Mirumachi has established the following increasing order for the different levels of cooperation: issue confrontation, ad hoc interaction, technical, risk-averting, and risk-taking. A third dimension, added later by Mirumachi and Allan [30], indicates the robustness of the political economy ranging from resource capture to resource sharing to resource alternatives.

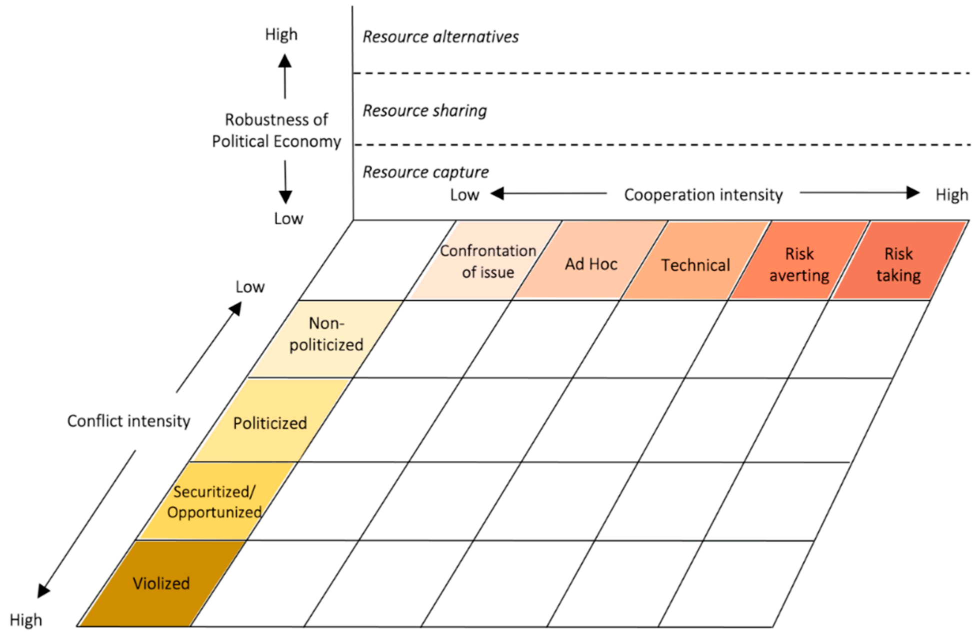

Figure 1. 3D TWINS model (Source: [30]. Adaptation: Karine Legrand).

As regions increasingly tap their available surface and groundwater resources, they have looked more and more to desalination as an option for augmenting natural water supplies. Over the past decade, as global desalination capacity has grown, a number of studies have looked at the role of desalination in hydropolitics, including in transboundary settings. Several scholars have indicated that desalination can reduce scarcity, thereby improving national water security and suggest that this is likely to lead to a "desecuritization" of water and a reduction in conflict (e.g., [32–34]).

In one of the first detailed analyses, Aviram et al. claim that desalination has the potential to significantly alter both the power dynamics between riparians as well as the incentives parties have to cooperate [10]. They note that desalination reduces stochasticity and, therefore, uncertainty regarding quantities, quality, location, and timing of water supplies. Given that these uncertainties are often factors contributing to conflict, they posit that desalination is likely to reduce conflict between parties. Moreover, the option of desalination means that parties may no longer consider the management of transboundary water resources as a zero-sum game. Putting this in the larger context of securitization literature, Walschot asserts that desalination allows parties to take desecuritizing measures regarding shared waters and to consider implementing cooperative policies [34].

While desalination increases the set of options available for cooperative interactions, Aviram et al. note that it is also something that parties can implement unilaterally, and thus, it can disincentivize or even obviate the need for cooperation [14]. The authors also use a TWINS framework to demonstrate the change in relations between Israel and Jordan —less conflictual and more cooperative—as parties increasingly adopted desalination.

Not all observers concur that desalination will reduce conflict. Several caution against treating desalination as a type of technological fix for water policy, including in transboundary settings (e.g., [35,36]). Feitelson and Rosenthal suggest that parties often adopt desalination specifically in order to avoid addressing difficult structural and/or political issues, leaving them to fester [9]. Petersen-Perlman et al. conjecture that desalination may lead to new conflicts, perhaps over the impacts of desalination, but do not expand on what these might be [11]. Phillips et al. highlight how desalination has failed to resolve Israeli–Palestinian water disputes and make the case that Israel's promotion of cooperation over desalination was actually a source of contention as Palestinians perceived it as entrenching obstinacy and unwillingness on the part of Israel to enter negotiations over reallocation of natural shared waters [37].

Katz presents an overview of the potential and several actual impacts of desalination on hydrodiplomacy and notes that desalination reduces both scarcity and variability, which are considered by different schools of thought as both drivers of conflict and drivers of cooperation; thus, desalination may have the effect of reducing both [12]. He also claims that having the option of desalination changes parties' best alternatives to negotiated agreements, and thus, their negotiation strategies. He presents examples from numerous cases around the world, both for increased and decreased cooperation. For instance, he presented cases of how desalination provided parties with increased flexibility in their relations with others, for instance, allowing for proposals for the development of joint desalination, water swaps, and other initiatives between the United States and Mexico and Israel and Jordan. However, he also showed how the option of desalination allowed Singapore to forego the renewal of a water supply agreement with Malaysia after it deemed Malaysian demands too extreme.

In terms of conflict, some scholars have noted the potential for desalination facilities to be a target of conflict (as was the case in Saudi Arabia [38]), for environmental impacts resulting from desalination (e.g., brine disposal) to be a source of conflict [39,40], or for conflict over issues of equity and cost-sharing related to desalination [35,41]. Such issues are common to many aspects of water infrastructure and management. Katz, however, presented real-world examples of how desalination can lead to new types of conflicts [12]. For instance, he showed how, with desalination, marginal water sources (e.g., brackish groundwater), as well as seawater quality, are now potentially critical to the provision of freshwater, and he demonstrated how disputes over both brackish water and seawater pollution have led to conflict in the case of Israeli–Palestinian relations. Indeed, the author highlighted what he calls a "saltwater-freshwater nexus" as a new aspect of freshwater management that needs to be coordinated in the era of desalination.

Several observers have also highlighted how large-scale desalination of seawater can alter, and perhaps even reverse, the underlying power dynamics between riparians. Most observers conclude that upstream parties have an asymmetric advantage over their downstream riparians, as, all else equal, they have the option of limiting flow or affecting quality. However, in the case of desalination, the dynamics favor the coastal areas, which tend to be downstream, giving them a unilateral advantage [8–10]. While such shifts in power dynamics have been noted by some, they have not been well studied, largely due to the limited empirical evidence available with such a nascent technology.

In sum, the impacts of desalination on both cooperation and conflict appear to be empirical issues. While there has been a fair amount of speculation about possible impacts and a small number of studies citing various anecdotal or case study evidence, there has been little in the way of systematic investigation of these impacts. This study attempts to begin addressing this gap in the literature.

3. Research Questions and Methods

3.1. Research Questions

Based on the existing literature, which suggests that desalination cannot be assumed to impact either conflict or cooperation in any pre-ordained or deterministic manner, we ask the overarching question of whether or not any patterns or trends can be seen from an empirical investigation of the data.

For the above question, we propose the following specific alternative research questions, which we test separately:

Q1. ***Does large-scale seawater desalination lead to more or less cooperation regarding transboundary water management?***

H1. *By reducing stochasticity in terms of water quantity and quality and, therefore, inducing greater flexibility in water supply management, large-scale seawater desalination technology should enhance cooperation over shared waters.*

H2. *By reducing stochasticity in terms of water quantity and quality and, therefore, inducing greater flexibility in water supply management, large-scale seawater desalination can enhance unilateral action, thereby reducing cooperation over shared waters.*

Similarly, the same question was asked regarding desalination's impact on conflict.

Q2. ***Does large-scale seawater desalination lead to more or less conflict over transboundary water management?***

H1. *By reducing stochasticity in terms of water quantity and quality and, therefore, inducing greater flexibility in water supply management, large-scale seawater desalination should reduce conflict over shared waters.*

H2. *By introducing new sources of water, as well as issues of equity and access, large-scale seawater desalination will increase conflict over shared waters.*

Moreover, a review of the existing literature on cooperation and conflict over transboundary water resources, in general, indicates that the processes and interactions that take place depends on the nature of the broader hydropolitical context. Thus, this paper developed a second research question:

Q3. ***Are the direction and scale of the impacts of desalination in terms of conflict and co-operation independent of the hydropolitical security complex in which they occur or, alternatively, are they a function of it?***

3.2. Methods

To answer the research questions and test the hypotheses, this research adopted a mixed-method (quantitative and qualitative) approach. In addressing the first two questions, we run different statistical tests with data collected and coded according to the TFDD protocol and the Basins-At-Risk (BAR) scale. To address the third question, we adopt the TWINS model to assess the contextual settings in which large-scale desalination and water interactions intertwine. This framework was applied after conducting an in-depth analysis of the larger historical and hydropolitical context.

This study looks at six case studies: Israel–Jordan–Palestine, Israel–Turkey, Republic of Cyprus–Turkish Republic of Northern Cyprus (henceforth Cyprus and Northern Cyprus), Singapore–Malaysia, Saudi Arabia–Jordan, and the United States–Mexico. These cases were chosen based on specific criteria, including the adoption of large-scale seawater desalination facilities by at least one of the parties in or affecting transboundary basins. Several potential cases, while interesting, were excluded from the study as they did not meet the criteria. The case of Israel–Turkey was included despite the two countries not having a shared basin because there were high-level negotiations over the possible import of water from Turkey by Israel that was affected by the option of desalination. Further, the case of Israel–Jordan–Palestine was analyzed both as a collective, as all three share the Jordan Basin, and as independent dyads (two country pairings): Israel–Jordan and Israel–Palestine.

To conduct the statistical analysis, we collected data on water interactions from the TFDD's database [18]. As mentioned, the data points are individual interactions and events between parties over water and are coded on an integer scale ranging from −7 to 7, representing increasing degrees of conflict (negative values) and cooperation (positive values). The databased covered the time period of 1948 to 2008. Given that large-scale desalination is a relatively recent development, we collected and coded events occurring between 2008 and 2018 according to TFDD protocols, working with the database managers at Oregon State University. Thus, our final database for analysis covered the years 1948–2018. We ran the analysis for each case study separately and for the group as a whole using two different datasets: the initial dataset covering the entire period (*"All Years"*) and a modified subset of this in which the time period included was limited to a maximum of 15 years before and after the initial adoption of large-scale desalination by at least one party (*"+/− 15 Years"*). The more limited dataset was undertaken under the presumption that it is better able to capture changes in interactions around desalination. In keeping with previous research, the analysis was performed using both the BAR scores and the anti-logs of these values in order to emphasize the increasingly large differences in intensity of events as the values increase (in absolute terms) (e.g., [15,26]). For the purpose of both brevity and consistency with the literature, we report only the results of the anti-log transformations. In terms of implications or conclusions to be drawn, results using the untransformed raw BAR scores did not differ in any meaningful way from those of the anti-log transformed data.

Three different statistical tests were undertaken to analyze different aspects of the data and in order to assess the robustness of any given finding. We used a chi-squared test to see if the periods pre and post-adoption of large-scale desalination differed in terms of the number of conflictual or cooperative interactions. The null hypothesis was that there was no difference.

Because analysis of the number of events gives little insight into the magnitude of the events, we also ran *t*-tests to evaluate whether the pre and post-periods differed in terms of intensity of conflictive or cooperative interactions, as measured by the mean BAR score in each period. As theory does not convincingly predict whether conflict or cooperation will change post-adoption of desalination, we ran two-tailed *t*-tests. We also ran one-tailed *t*-tests based on whichever direction was more dominant (i.e., more conflict or more cooperation) in the post-desalination period.

Finally, a regression discontinuity analysis was performed to see if the trends in interactions shifted with the adoption of desalination. For this analysis, the regressions ran were:

$$BAR = \beta_0 + \beta_1 Year + \beta_2\, Desal + \varepsilon \tag{1}$$

$$BAR = \beta_0 + \beta_1 Year + \beta_2\, Desal + \beta_3\, Desal{*}Year + \varepsilon \tag{2}$$

where:

BAR = (the anti-log transformed) BAR score
Year = the year of observation, normalized relative to the first year of adoption of desalination for each case
Desal = a dummy variable indicating whether the year was pre or post-adoption of desalination
*Desal*Year* = an interaction term
ε = error term

For the aggregated case studies, the regression was run as a fixed effects regression, clustered by case. In terms of interpreting the coefficients, the value of β_1 represents the slope of the pre-desal period, β_2 represents a shift in the year that desalination was adopted, and β_3 represents any change in slopes between the pre and post-desalination periods. Table 1 offers a summary of these different statistical tests.

Table 1. Summary of the statistical tests conducted.

Statistical Test	Question	Hypothesis or Parameters
Chi-squared test	Do the pre and post-desal periods differ in terms of the number of conflictive or cooperative events?	Null hypothesis–H_0 = no difference Alternative hypothesis–Ha = difference
t-tests	Do the pre and post-desal periods differ in terms of the intensity of conflictive (cooperative) events, as measured by mean BAR score?	*One-tailed t-tests* Null hypothesis–H_0 = no difference Alternative hypothesis–Ha = the adoption of desalination does negatively (positively) affect the mean value of water interactions
		Two-tailed t-tests Null hypothesis–H_0 = no difference Alternative hypothesis–Ha = difference
Discontinuity Regression	Does the trend in average yearly BAR score shift in the post-desal period?	Dependent Variable: • Mean annual BAR score Independent Variables: • Year (continuous integer) • Desal (dummy) • Interaction terms

In terms of the third research question, we adopted a qualitative approach using the TWINS framework. To do so, we compiled data from primary sources such as official documents, statements, and reports from different governments and international organizations. We also reviewed secondary sources such as scientific articles as well as newspaper articles, and other media sources. Based on this data, the research established a timeline for each case study that indicated distinct periods in hydropolitical relations between the riparian actors.

The analysis relies on qualitative analysis of documents that include identifying, categorizing, and discussing meanings, patterns, and themes in texts. Each relevant interaction was examined to understand the different periods characterizing transboundary water interactions between two riparian actors in order to establish where in the TWINS matrix each period best fits. As mentioned, the TWINS approach makes it possible to consider cooperation and conflict situations simultaneously. It can also help draw the robustness of the political economy of the actors to place water interactions into their socio-political context.

4. Results

4.1. Quantitative Analysis

The complete database of all six case studies, *All Years*, included over 500 data points, each representing an interaction between parties. This number declined to less than 400 when restricting the database to include only the time period covering 15 years before and after the adoption of desalination by at least one of the parties *(+/− 15 Years*). When comparing positive (cooperative) and negative (conflictive) BAR score values, the number of data points declined even a bit more, given that a number of observations were coded with a value of zero, indicating that these interactions were neutral and did not indicate either cooperation or conflict. Of the available data, the overwhelming majority was dominated by two case studies: Israel–Jordan–Palestine and the US–Mexico. Two other case studies—Saudi Arabia–Jordan and Cyprus–Northern Cyprus—had very few data points, and no statistical analysis was possible for these cases. All tests on the pooled data were run with and without these cases, and the results did not differ significantly. Summary statistics for the data are provided in Table A1 in the Appendix A.

Table 2 below shows the percentage of observations that were cooperative in both the pre and post-desalination periods for both datasets. Overall, there was an increase in cooperative events relative to conflictive ones in the post-desalination period, but this was not at all consistent across cases. Furthermore, the Saudi Arabia–Jordan case did not have any observations at all for the pre-desal period, given a small number of observations and Saudi Arabia's long history of desalination, and so no such comparison was possible. The Cyprus–Northern Cyprus case had only a few interactions in each period, all of which were cooperative, and so the share of cooperative events did not change.

Table 2. Percent of Positive (Cooperative) Interactions Pre and Post-Desalination.

	All Years		***+/− 15 Years***	
	% Positive Pre-Desal	**% Positive Post-Desal**	**% Positive Pre-Desal**	**% Positive Post-Desal**
All Observations	59%	**66%**	62%	**65%**
Israel–Jordan–Palestine	**54%**	44%	**64%**	44%
Israel–Jordan	51%	**67%**	61%	**67%**
Israel–Palestine	**57%**	25%	**62%**	25%
US–Mexico	58%	**75%**	46%	**75%**
Saudi Arabia–Jordan	n.a.	78%	n.a.	78%
Cyprus–Northern Cyprus	100%	100%	100%	100%
Israel–Turkey	**82%**	0%	**82%**	0%
Singapore–Malaysia	**68%**	50%	**56%**	50%

Note: Bold indicates the period with the higher value. Values rounded to the nearest whole number. n.a.: not available.

As is shown in Table 3 below, in terms of the chi-squared tests, using the *All Years* dataset, only the US–Mexico and the Israel–Turkey cases were significant at the 5% level. When restricting the database to only +/− *15 Years* the Israel–Palestine case was also significant. In the case of US–Mexico interactions, there was a significant reduction in conflictive events relatively. However, in both the Israel–Turkey and Israel–Palestine cases, there was an increase in conflictive interactions, though in both cases, the number of data points included was very small. Looking at the pooled cases, irrespective of case, the difference in pre- and post-desalination periods were significant at the 10% level with the entire database, but even this level of significance dropped when restricting the database to +/− *15 Years.* In sum, there does not appear to be any strong trend one way or another in terms of either changing the volume of cooperation or conflict between parties. The fact that both the number of cases and the number of observations is limited, both in specific cases and when aggregating cases, is certainly a limiting factor, but the fact that some cases are statistically significant but do not agree in terms of the direction of the impact raises questions about the generalizability of any findings.

While the chi-square tests only for the difference in the number of events, positive or negative, the *t*-tests take into account the intensity of the type of cooperation or conflict by looking at the BAR score for each event and not just its sign. Using the entire, *All Years*, dataset, the Singapore–Malaysia case was the only one significant at the 5% level, as was the pooled data of all cases (Table 4). However, when using the limited time frame dataset, +/− *15 Years*, the Singapore–Malaysia case was no longer significant, but the US–Mexico and Israel–Palestine cases were, as was the joint Israel–Jordan–Palestine case, which includes the data points in the more limited Israel–Palestine one. The aggregated pool of all cases was statistically significant at the 5% level in the *All Years* dataset but not in the more restrictive +/− *15 Years* one. Again, there did not appear to be a strong case for a consistent trend, with the mean BAR score increasing in the post-desalination period in the case of US–Mexico but decreasing in the other cases.

Table 3. Summary of chi-squared test results.

	All Years			+/— 15 Years		
	N	**Chi-Squared Value**	***p*-Value**	**N**	**Chi-Squared Value**	***p*-Value**
All Observations	442	3.250	0.072 *	323	0.702	0.402
Israel–Jordan–Palestine	222	0.661	0.416	153	2.922	0.087
Israel–Jordan	176	0.895	0.344	111	0.131	0.718
Israel–Palestine	52	3.301	0.069	37	4.669	0.031 **
US–Mexico	143	7.252	0.007 ***	107	21.771	0.000 ***
Saudi Arabia–Jordan	9	n.a.	n.a.	2	n.a.	n.a.
Cyprus–Northern Cyprus	5	n.a.	n.a.	6	n.a.	n.a.
Israel–Turkey	23	4.500	0.034 **	23	4.500	0.034 **
Singapore–Malaysia	38	2.438	0.118	32	0.254	0.614

Notes: N = number of observations with either a positive or negative value. Observations with a value of 0 (i.e., neutral) were dropped from the analysis. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, n.a.: not available.

Table 4. Summary of one-tailed and two-tailed *t*-tests.

	All Years			+/— 15 Years		
	***t*-Stat**	***p*-Value 1-Tail**	***p*-Value 2-Tail**	***t*-Stat**	***p*-Value 1-Tail**	***p*-Value 2-Tail**
All Observations	−1.696	0.046 **	0.091	−0.870	0.193	0.385
Israel–Jordan–Palestine	0.596	0.278	0.556	1.814	0.040 **	0.081 *
Israel–Jordan	−0.909	0.191	0.381	0.061	0.476	0.953
Israel–Palestine	1.462	0.079 *	0.158	1.859	0.039 **	0.077 *
US–Mexico	−0.854	0.197	0.394	−3.054	0.001 ***	0.003 ***
Saudi Arabia–Jordan	n.a	n.a	n.a	n.a	n.a	n.a
Cyprus–Northern Cyprus	−1.540	0.111	0.221	−1.540	0.111	0.221
Israel–Turkey	n.a	n.a	n.a	n.a	n.a	n.a
Singapore–Malaysia	1.971	0.027 **	0.054 *	0.696	0.245	0.490

Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$, n.a.: not available.

For the discontinuity regressions, we present here only the results for the second more flexible functional form, allowing for shifts in slope between the two periods (i.e., Equation (2)). This is both for reasons of brevity and because of the adoption of desalination did have a substantial impact on relations, it is unlikely to manifest itself as an immediate shift in relations but rather as a shift in the trajectory of relations in the post-adoption period.

For the pooled data, regressions were run with and without the case of Saudi Arabia–Jordan given that it had no pre-desalination observations. No regressions were possible for the Saudi Arabia–Jordan and Cyprus–Northern Cyprus case studies, given the small number of observations in each.

Using the *All Years* dataset, the desal dummy variable was statistically significant at the 5% level for all cases except that of Israel–Jordan, and was statistically significant at the 10% level for the pool data when the Saudi Arabia–Jordan case was dropped (Table 5). The effect of the shift, however, differed between cases.

Table 5. Regressions using the *All Years* dataset.

	All Cases	All Cases w/o SA-JD	ISR-JOR-PAL	ISR-JOR	ISR-PAL	USA-MEX	SGP-MYS
Year	−0.670 **	−0.670 **	0.077	−0.144	0.0438	−2.038 **	6.858 ***
	(−0.279)	(−0.279)	(−0.119)	(−0.253)	(−0.119)	(−0.872)	(−2.442)
Desal	3.252	16.50 *	−17.47 ***	−17.7	−13.22 ***	34.50 **	71.79 **
	(−13.1)	(−9.728)	(−5.662)	(−10.68)	(−5.028)	(−17.18)	(−28.44)
Desal*Year	2.454	−0.445	1.612	1.748	1.256	0.187	6.830 ***
	(−2.332)	(−1.166)	(−1.083)	(−1.579)	(−1.192)	(−2.189)	(−2.446)
Constant	6.338	6.338	13.21 ***	12.53	11.84 ***	−0.975	−69.76 **
	(−3.905)	(−3.905)	(−4.103)	(−8.659)	(−3.936)	(−10.9)	(−28.43)
R-squared	0.028	0.024	0.005	0.012	0.003	0.086	0.621

Note: values in parentheses are robust standard errors. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

The interaction variable, representing any change in slope in the post-adoption period, was significant at the 5% level only in the case of Singapore–Malaysia, indicating that the post-adoption period was more cooperative (or less conflictive). In addition, despite not having statistically significant results, the sign on the coefficients changed from negative to positive between the pre and post-desalination periods for the cases of Israel–Jordan and US–Mexico.

However, even these modest results were not consistent when the dataset was restricted to only *+/− 15 Years* (Table 6). For these data, the only variable statistically significant at the 5% level was the desal dummy in the US–Mexico case. No cases showed a statistically significant post-desal trend at the 5% level, though the Israel–Jordan–Palestinian case did show a positive trend that was significant at the 10% level. The lack of statistical significance is perhaps due to the small sample size, especially in the individual cases. However, the lack of consistency between cases, even in terms of the signs of the coefficients, is another indicator that there does not appear to be any single impact of the adoption of desalination that is generalizable across cases. The Singapore–Malaysia case, which was highly significant when using the *All Years* dataset, was not at all significant when using the dataset covering only the period 15 years prior to and following the adoption of desalination. Moreover, the sign on the coefficient of the variable "Year", representing the trend pre-desalination switched from positive to negative when moving to the more restrictive dataset.

Table 6. Regressions using the *+/− 15 Years* dataset.

	All Cases	All Cases w/o SA-JD	ISR-JOR-PAL	ISR-JOR	ISR-PAL	USA-MEX	SGP-MYS
Year	−0.488	−0.488	−0.975	−0.339	−0.665	−2.017	−0.491
	(−0.457)	(−0.457)	(−0.853)	(−0.622)	(−1.06)	(−1.887)	(−0.406)
Desal	15.77	15.53	−8.474	−16.06 *	−7.325	31.80 **	1.996
	(−9.616)	(−9.817)	(−6.609)	(−9.562)	(−7.596)	(−13.72)	(−2.758)
Desal*Year	−0.742	−0.669	2.664 *	1.943	1.965	0.166	0.463
	(−1.252)	(−1.351)	(−1.376)	(−1.691)	(−1.595)	(−2.761)	(−0.426)
Constant	7.466 **	7.466 **	4.219	10.89	5.943	1.72	0.0279
	(−3.203)	(−3.203)	(−5.326)	(−7.185)	(−6.915)	(−3.238)	(−2.658)
R-squared	0.006	0.006	0.008	0.009	0.005	0.017	0.041

Note: values in parentheses are robust standard errors. ** $p < 0.05$, * $p < 0.1$.

4.2. Qualitative Analysis

The statistical analysis of transboundary relations has inherent limitations, even in cases with large numbers of observations. Qualitative analysis, such as the TWINS framework of analysis, was developed specifically to address the shortcomings of analyses like most of the statistical analyses using the BAR scores and other similar databases that treat conflict and cooperation as a continuum. It is also not limited by sample size issues in the way that quantitative analyses are. It is possible that both conflict and cooperation increased or decreased over time or that they moved in opposite directions. Given the small sample sizes in our statistical analysis, it was not possible to run separate tests using only cooperative interactions and only conflictive ones. Qualitative assessments, however, can address these nuances. They can also give a perspective that statistical tests cannot. For instance, measuring the number of events or the intensity of these events still may not capture how important any specific event was to the affected populations or policymakers.

In order to address the second research question, this research evaluated where cooperation has increased or decreased and where conflict has increased and decreased following the advent of large-scale desalination. Given the objective of the TWINS framework to allow for in-depth and nuanced analysis, it is in some sense perhaps not in keeping with the intent of the model to summarize all interactions in one label. However, in an attempt to succinctly highlight the primary trajectories of the relations between parties post-adoption of desalination, we summarize these outcomes using a 2 × 2 matrix indicating more or less conflict and more or less cooperation post-adoption of desalination relative to the pre-desalination period. As indicated in Table 7, outcomes differ substantially between cases.

Table 7. Summary table of water interactions.

	Less Cooperation	**More Cooperation**
More Conflict	• Singapore–Malaysia	
Less Conflict	• Israel–Palestine • Cyprus–Northern Cyprus • Israel–Turkey	• Israel–Jordan • US–Mexico • Saudi Arabia–Jordan

In three cases out of seven (Israel–Jordan, US–Mexico, and Saudi Arabia–Jordan), the findings indicate an increase in cooperation and a decrease in conflict after introducing large-scale desalination. Using the terms of the TWINS framework, these three cases are characterized by an overall positive hydropolitical security complex with active cooperation and joint risk-averting and risk-taking actions. For example, in the case of Israel–Jordan, reduced scarcity facilitated Israel's willingness to supply Jordan with more water from the Jordan basin and to agree to initiatives such as the development of a joint desalination mega-project supplying water to Jordan and developing a canal between the Red Sea and the Dead Sea to stabilize the levels in the latter. While the project is currently on hold due to questions about costs and environmental concerns, other agreements have progressed, such as one signed in 2021 involving exchanges of desalinated water and renewable energy (see, [42,43]). Similarly, in the case of US–Mexico relations, the countries have discussed the development of joint desalination facilities and even the US building a desalination plant in Mexico in lieu of its obligations. Thus, the advent of desalination has led to both new agreements and more flexibility and options for meeting obligations of existing agreements. In the case of Saudi Arabia–Jordan), conflict was somewhat reduced, though the conflict that did exist was of relatively low intensity and frequency in any case.

While in-depth analysis of the case studies is not possible in an academic article (for detailed analysis of the case studies, see [44]), Figure 2 presents a graphical example of the TWINS assessment of the progress of one case study, Israel–Jordan. The numbers 1–5 indicate different periods of time:

- Period 1 (1948–1967)
- Period 2 (1967–1994)
- Period 3 (1994–2005)
- Period 4 (2005–2017)
- Period 5 (2017–Present)

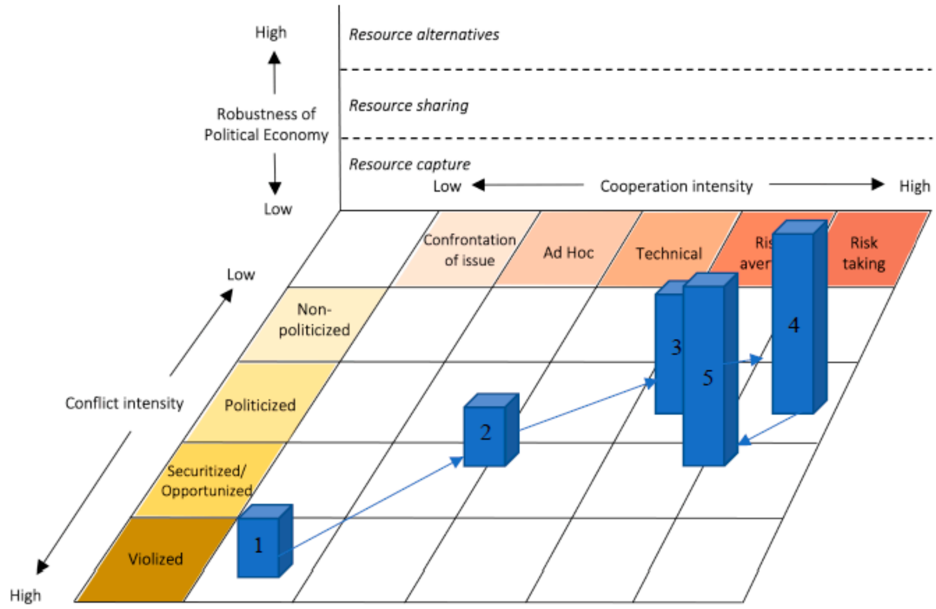

Figure 2. TWINS representation of Israel–Jordan interactions over transboundary waters.

Desalination was specifically mentioned in the Israeli–Jordanian peace agreement of 1994, and Israel began large-scale desalination in 2005. As can be seen in Figure 2, there was significant movement away from volatized conflict and securitization of water and towards joint risk-taking in cooperative initiatives, though arguably some increasing politicization occurred in recent years.

Three other cases (Israel–Palestine, Cyprus–Northern Cyprus, and Israel–Turkey) evidenced a decrease in both cooperation and in conflict following the introduction of large-scale desalination. These three cases are characterized by a hydropolitical security complex with long-lasting tensions with some cooperation, but with no real risk-averting or risk-taking actions. It was indicative of desalination, allowing for a disengagement between the parties, generally with one party engaging in "unilateral action". In the case of Israel–Palestine, for instance, Israel developed desalination and, as it had with Jordan, offered to sell Palestinians desalinated water, but because rights to natural waters are still unresolved, the offer was largely perceived by Palestinians as a strategy by Israeli to avoid negotiating reallocation [37]. Rather than result in more cooperation, the Palestinians are pursuing their own desalination plant in the Gaza Strip, though progress on construction has been delayed due to security concerns by Israel regarding the materials needed to build it [45].

In the case of Israel–Turkey relations, Israel had been negotiating with Turkey for the import of water, but this was abandoned once it began the operation of large-scale seawater desalination. In the case of Cyprus–Northern Cyprus, discussions between the two parties of the possible development of joint desalination or the purchase of desalinated water by the latter from the former led to Turkey developing an underwater pipeline to supply water to Northern Cyprus. Several observers have suggested this move was an attempt by Turkey to keep Northern Cyprus under its patronage (e.g., [46,47]). Following this, interactions between Cyprus and Northern Cyprus over water have decreased overall, with less cooperation but also without significant conflict.

The case of Singapore–Malaysia evidences a decrease in cooperation and an increase in tensions. Singapore did not renew a long-standing water purchase agreement with Malaysia after what it considered unreasonable demands regarding the price of water and attempts by Malaysia to use water as political leverage to extract concessions on other issues [48]. As a result, Singapore accelerated and intensified its development of desalination and began a process of reducing its dependency on Malaysia for water. The result has been an overall deterioration in Singaporean–Malaysian relations concerning water, with heightened rhetoric, both parties accusing each other of unreasonable demands. Using the TWINs framework, this case is characterized by an overall negative hydropolitical security complex with emerging tensions that lessen cooperation and little if any intention of joint risk-averting or risk-taking actions.

These findings support the theory that the nature of the hydropolitical security complex could determine the likelihood and intensity of cooperative or non-cooperative water interactions between riparian actors in the advent of large-scale seawater desalination.

When comparing case studies, findings indicate several interesting patterns. For example, in both the Israel–Palestine case and the Singapore–Malaysia case, existing agreements were either incomplete or about to expire, and desalination allowed for unilateral action and disengagement between the parties. While in the case of Israel–Jordan and US–Mexico, the water-sharing treaties were in effect, and desalination offered additional opportunities to meet treaty obligations and even to develop cooperative initiatives that went beyond such obligations.

To sum up the findings from the qualitative assessment, it seems that here too, there is no common trend in water interactions both in terms of impact on cooperation and on conflict between parties. The results vary between case studies and seem to be very much subject to the nature of the overall political and hydropolitical context.

5. Discussion

The purpose of this paper was to study the impact of large-scale desalination on transboundary water interactions. As there are no previous quantitative research studies looking at this, we took a quantitative approach, anchoring the methods in the preexisting literature as much as possible. In light of the limitations both of the databases available and the small sample sizes, given the relative newness of large-scale desalination, we supplemented the quantitative assessment with a qualitative assessment based on an extensive review of the official governmental, academic, and grey literature.

In terms of the quantitative analysis, there were relatively few statistically significant results. Much of this can be attributed to both the limited number of case studies available and the small number of observations in some of these. Moreover, there were correlations between the cases, as three out of six involved a single country, Israel. Thus, one cannot treat them as independent of one another.

Even with these limitations, it was possible to see that the results varied between cases, between datasets (time-periods covered), and between the choice of statistical test. There was little consistency even in terms of the direction of influence, i.e., whether desalination led to more or less conflict or cooperation. Moreover, the more detailed the analysis goes in terms of the tests used—from chi-squared, looking just at the number of events by type, to *t*-tests looking at changes in the intensity of interactions, to regression discontinuity, looking at the trajectory of these interactions over time—the less significant the results were.

The US–Mexico case is the only recurrent case with significant results in all three different tests. In all three, the findings are consistent with a positive correlation between desalination and positive interactions. This case supports the qualitative findings of Wilder et al. [40,49] and suggestions by some that desalination is likely to desecuritize transboundary water relations and/or reduce conflict (e.g., [10,32]).

In the Singapore–Malaysia case, the fact that both the statistical significance and the sign on the coefficients in the regression were not consistent between datasets highlights the importance of the time period used for any analysis. While not statistically significant, the negative sign on the coefficient for the pre-desalination period combined with positive coefficients on the dummy and interaction terms would seem to support the hypothesis that desalination can reduce conflict and/or increase cooperation. The fact that overall positive interactions between the two decreased in the post-desalination period (Table 2) is consistent with the hypothesis that desalination may reduce conflict but also allow for unilateral actions, also reducing cooperation [10,12].

Other cases, however, including those with statistically significant results in at least some of the tests (e.g., Israel–Palestine), do not support these conclusions. Rather, they are consistent with the assessments of others (e.g., [11,12], that in some cases desalination may, in fact, lead to new and/or more intense conflicts.

The differences between cases, including between different parties in the same basin (i.e., Israel–Jordan and Israel–Palestine), and the lack of robustness and consistency between the different datasets and tests, seem to indicate that desalination does not have any one type of deterministic impact on conflict or cooperation between parties. Rather, its impact is likely to be affected by the broader geopolitical setting in which overall riparian relations take place. This conclusion is supported by the qualitative assessment as well.

Only two case studies sustained the theory of enhanced cooperation and decreased conflict (US–Mexico and Israel–Jordan). The case of Saudi Arabia–Jordan exhibited somewhat less conflict from what were pretty low-level interactions in any case. This may also reflect the fact that the shared aquifer between the two countries is far from Saudi population centers and, thus, not a critical resource for the country's water supply.

The US–Mexico, Israel–Jordan, Israel–Palestine, and Singapore–Malaysia cases were all governed by water treaties. However, in the case of Israel–Palestine, the treaty was an interim one that left many outstanding issues between the parties unresolved, while in the case of Singapore–Malaysia, one of the treaties expired, and the parties did not agree on terms for its renewal. In both of these latter cases, at least one of the parties decided to increase reliance on desalination rather than continue negotiations with their neighbor. This supports the claim that desalination may reduce cooperation by virtue of allowing for unilateral action and disengagement rather than negotiated settlement and cooperation. The case of Singapore–Malaysia also indicates that a reduction in conflict cannot be assumed (thus, it contravenes a supposition made in Aviram et al. [10]).

Both the Singapore–Malaysia and the Cyprus–Northern Cyprus cases revolve around large-scale water transfers. In the former case, desalination was adopted by Singapore as an option to reduce its dependency on Malaysia for water imports. In the latter, water imports to Northern Cyprus were supplied by Turkey in what is largely seen as an attempt to reduce the potential for cooperation between Northern Cyprus and Cyprus. While the outcomes differed in terms of the adoption of desalination, both resulted in decreased cooperation.

In undertaking the qualitative assessment, one shortcoming of the TWINS model became apparent, which is that it is not possible to accommodate two points of view for the status of relations. For example, in evaluating levels of politicization or securitization, scholars and perhaps the parties themselves may differ in their assessments (see, for example, differing views presented by Schäfer [50] and Aviram et al. [10].

Returning to the third research question asked in this study, the qualitative assessments certainly seem to support the conclusion that the impacts of desalination are very much context-dependent and functions of the broader political relations between partners.

6. Conclusions

Desalination is increasingly being adopted by countries as a tactic for dealing with water scarcity and water quality issues, and several observers have hypothesized about its potential role in hydropolitical relations between countries. To date, there has been little empirical literature examining this. This sought to address this gap in the literature by asking whether empirical analysis could identify any specific trends in terms of the impact of desalination on levels of either cooperation or conflict between parties sharing water. Because large-scale desalination is relatively rare, there were relatively few cases to study, some of which had little in terms of quantitative data to analyze. Moreover, the bulk of the observations came from specific case studies, which involved asymmetric socio-economic relations between parties. Thus, it is difficult to draw any strong generalizable conclusions. It may be that trends emerge only when there is a critical mass of desalination in different areas (for instance, if more than one party becomes dependent on desalination or if desalination is of such a scale that the disposal of brine becomes a significant transboundary issue).

That said, the analysis did seem to shed light on the research questions presented. The results indicate that desalination has both the potential for reduced conflict and increased cooperation, but also for reduced cooperation due to unilateral actions and even for increased conflict in some circumstances. Rather than see the lack of consistent and statistically significant results as a limitation of the findings, the fact that different tests and different cases produced different results seems to refute the supposition that desalination will have any strong deterministic impacts in terms of the amount or intensity of conflict or cooperation over transboundary waters. The qualitative analysis, which is perhaps less systematic but more nuanced, only reinforces this conclusion and that the outcome will largely be a function of the broader geopolitical context.

As desalination is more widely adopted, there will be opportunities to analyze additional and a more diverse set of cases, and thus, perhaps to better understand the various conditions under which desalination may lead to one outcome or another. Hopefully, this study provides a basis or reference point for such future work.

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Appendix A

Table A1. Summary Statistics.

		All Cases			***+/− 15 Years***		
	Number of Observations	**Pre-Desal**	**Post-Desal**	**Total**	**Pre-Desal**	**Post-Desal**	**Total**
All Observations	Total Events	394	127	521	275	120	395
	Positive BAR events	199	69	268	140	65	205
	Negative BAR events	141	35	176	85	35	118
	Ratio Positive//Negative	1.4	2.0	1.5	1.6	1.9	1.7
Israel–Jordan–Palestine	Total Events	237	23	260	163	23	186
	Positive BAR events	111	7	118	88	7	95
	Negative BAR events	95	9	104	49	9	58
	Ratio Positive//Negative	1.2	0.8	1.1	1.8	0.8	1.6
Israel–Jordan	Total Events	187	11	198	117	11	128
	Positive BAR events	85	6	91	62	6	68
	Negative BAR events	82	3	85	40	3	43
	Ratio Positive//Negative	1.0	2.0	1.1	1.6	2.0	1.6

Table A1. *Cont.*

	Number of Observations	All Cases			+/− 15 Years		
		Pre-Desal	Post-Desal	Total	Pre-Desal	Post-Desal	Total
Israel–Palestine	Total Events	60	14	74	42	14	56
	Positive BAR events	25	2	27	18	2	20
	Negative BAR events	19	6	25	11	6	17
	Ratio Positive//Negative	1.3	0.3	1.1	1.6	0.3	1.2
US–Mexico	Total Events	86	72	158	48	72	120
	Positive BAR events	48	45	93	21	46	67
	Negative BAR events	35	15	50	25	15	40
	Ratio Positive//Negative	1.4	3.0	1.9	0.8	3.1	1.7
Saudi Arabia–Jordan	Total Events	0	9	9	0	2	2
	Positive BAR events	0	7	7	0	7	7
	Negative BAR events	0	2	2	0	2	2
	Ratio Positive//Negative	n.a.	3.5	3.5	n.a.	3.5	3.5
Cyprus-Northern Cyprus	Total Events	7	2	9	7	2	9
	Positive BAR events	7	2	9	4	2	6
	Negative BAR events	0	0	0	0	0	0
	Ratio Positive//Negative	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Israel–Turkey	Total Events	28	1	29	28	1	29
	Positive BAR events	18	0	18	18	0	18
	Negative BAR events	4	1	5	4	1	5
	Ratio Positive//Negative	4.5	0.0	3.6	4.5	0.0	3.6
Singapore–Malaysia	Total Events	36	20	56	29	20	49
	Positive BAR events	15	8	23	9	8	17
	Negative BAR events	7	8	15	7	8	15
	Ratio Positive//Negative	2.1	1.0	1.5	1.3	1.0	1.1

Note: Total number of events may not equal the sum of positive and negative events as they also include interactions with a neutral (i.e., 0) value. n.a.: not available.

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