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Synthesis Paper

Are intra- and inter-basin water transfers a sustainable policy intervention for addressing water scarcity?

Logan Purvis, Ariel Dinar*

School of Public Policy, University of California, Riverside, United States

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ABSTRACT

Water scarcity affects many countries around the world, and increases in severity over time as populations grow and climate change further intensifies. Governments and water regulators address increased water scarcity in a regional setting by introducing policy interventions, including non-structural, such as pricing mechanisms and quotas to affect demand, and supply management means, such as water storage and extraction. One of the most extreme policy interventions is to build infrastructure to move water from locations where it is abundant to locations facing scarcity. Such interventions are known as intra- and inter-basin transfers (IBTs) of water and have been quite frequently practiced in many river basins around the world in recent years. In moving water from one place to another benefits and costs are realized, some of which are private and some are public in nature. The objective of this paper is to discern whether or not the documented IBTs have been sustainable in addressing scarcity. Since very few quantitative cost benefit analyses are available for IBTs, we apply a variation of the QUAlitative Structural Approach for Ranking (QUASAR) method to 121 studies of documented IBTs within 40 territories and basins around the world, using five attributes of impact that were found to be associated with the transfers. Our findings suggest that the majority of the IBTs have been associated with overall negligible or negative impacts on the water-exporting regions, the water-transmitting regions, or the water-importing regions within the basins studied. Our findings also suggest that IBTs that were meant to relieve higher levels of water scarcity in the importing regions might be more prone to overall negative impacts.

1. Introduction

Water scarcity levels, which can be measured by several metrics [6], vary across geographical locations, and over time. Regional differences in water supply and availability occur for various reasons. These include natural environmental impacts, human interventions (which affect the quality of water and the ability to handle and manage water at the country, state, county, and city levels), and changes in demand due to population growth and changes in human lifestyle [9].

Several assessments of spatial and intertemporal water scarcity levels [38,47] suggest that by 2050, economic growth and population change alone could lead to an additional 1.8 billion people living under various levels of water stress, with the majority in developing countries. The strongest climate impacts on water stress are observed in Africa, but strong impacts also occur throughout Europe, Southeast Asia, and North America [38]. Over 2 billion people live in countries experiencing already high water stress, and about 4 billion people experience severe water scarcity during at least one month of the year [47].[1] An assessment of water demands by sectors is provided by Amarasinghe and Smakhtin [2], who examine how closely past projected withdrawals match current actual water withdrawals. By comparing six water demand projections (WPDs) conducted before 1990 and seven conducted after 1990 they show that the pre-1990 WDPs, based on population as the main driver of change and unrealistic assumptions of sectoral water use norms, overpredicted current water use by 20 to 130%. The post-1990 WDPs were based on sophisticated modeling frameworks, considering many exogenous and endogenous drivers of food and water supply and demand of different sectors. However, the post-1990 WDPs of the "business as usual" scenarios show substantial underestimation globally, and large deviations for sectors and countries from the current water-use patterns; the sustainable water use scenarios are even more downward biased.

Clearly, supply of water in many parts of the world lags behind the demand under existing conditions and the actual use by sectors. The substantial reduction (including deterioration in water quality) in the available renewable water resources over time and the increase in

* Corresponding author.
E-mail address: adinar@ucr.edu (A. Dinar).

[1] Stress = 1000–1700; Scarcity = 500–1000; Severe scarcity≤500 m^3/person per year.

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water-consuming economic activities (e.g., food production, increase in standards of living, deterioration in water quality) has led to a widening gap between the water quantities supplied and demanded.

These trends indicate a clear need for effective policy interventions. Water scarcity at the country, state, county, and city levels could be addressed by using different policy intervention mechanisms directed both at demand- and supply-side management. Demand-side management policies include various types of water quotas, various water pricing schemes (increasing block rate to reduce residential water use), and incentives (subsidies) for adoption of water-efficient technologies [13]. For supply-side management, policies include public investment in water supply, including manufacturing of water from the ocean (desalination) and treating wastewater to potable conditions for human consumption, or treating wastewater for use in agriculture or for aquifer recharge [16,33]. Many studies have been conducted to assess the efficiency of such policy interventions in specific regions or countries [20,30].

One major supply-side management policy that has been practiced in many parts of the world for quite some time is the transfer of water from locations where it is relatively abundant to locations where it is relatively scarce, both within one river basin (intra-), or between discrete river basins (inter-). Inter- and intra-basin transfers are simply "the transfer of water from one basin to another distinct basin or river catchment, or a sub-basin within a shared basin or river reach, respectively" [22].[2] This policy intervention involves massive investments in infrastructure and storage, and is different from a policy that allows the introduction of water trade for marketing of water among water rights holders, using existing conveyance infrastructure. For example, the National River Linking Plan (NRLP) is being developed by the government of India to resolve water scarcity across states and various river basins [26]. Some of the transfers in the Indian subcontinent do exist and some are in the planning phase. NRLP includes 30 links (IBTs) to connect 37 rivers across the sub-continent through a network of nearly 3000 storage dams, all of which form a gigantic a national water grid.

In another recent study Shumilova et al. [39] review water transfer megaprojects (WTMP) defined as large-scale engineering interventions to divert water within and between river basins. Such projects are mainly multi-purpose large-scale agricultural and energy schemes. The study includes 34 operating and 76 planned, or under construction, WTMPs. The authors estimate a total volume of 1,910 km^3 per year of all 110 mentioned WTMPs in North America, Asia, and Africa, once realized. Snaddon et al. [40] provide a comprehensive global list of existing and proposed IBTs (at the time of the publication of their study). The study reviews the capacity and the possible ecological consequences of individual IBTs by countries and river basins. This study reviews 51 existing IBTs with a total capacity of 1316.5 km^3 per year (16, 14, 2, 4, 9, 6 in Africa, North America, South America, Asia, Oceania, and Europe, respectively). Fifty-three additional proposed IBTs were identified in that study, some of which without information on the volume if water to be transferred. Another, more recent, assessment of the extent of water transfers by IBTs is provided by Gupta and Zaag [22], suggesting that in the year 2000, inter-basin water transfers diverted about 14% of all global water withdrawals. There are proposed schemes, which if implemented, IBT of water would represent more than a quarter of all water withdrawals in the world by the year 2025.[3]

[2] From hereafter, we will use the acronym IBT for both intra- and inter-basin transfers.

[3] We have not been able to find recently published studies with updated accounts of existing and planned IBTs. Perhaps, the fact that IBT projects are very long-term could suggest that the number of observed IBTs in the existing studies that we present from the early 2000s did not increase much in the past 10–15 years since the publication of the works we report.

As it appears, IBTs have been considered, planned and implemented in many parts of the world. What drives policy-makers to advance IBTs as a possible solution to water scarcity? The ultimate failure (or partial success) of the demand management interventions, or locations of water scarce regions which do not allow producing water from the ocean or treat and reuse wastewater, open the door for the public to accept IBTs as a policy intervention. In addition, IBTs can be supported due to the presence of short- and long-term concerns by policy makers, such as climate change and population growth which may affect the availability of water in certain territories and basins.

While many studies have been undertaken in order to estimate the efficiency, effectiveness, and social cost of policy interventions in the form of water pricing and water quotas, as was indicated earlier in the paper, relatively few studies address the sustainability of IBT policies. Most of the published work on IBTs evaluate particular aspects of selected IBTs or document various IBTs, or even take stock of all IBTs [41,48,43,29]. However, they do not conduct a comparative analysis of the impacts of IBTs to allow any type of assessment of the sustainability of IBT as a policy intervention.

IBTs have been practiced and reported in the literature, but there is a lack of a global analysis of IBTs as a water-scarcity policy. IBT affects the local population and the environment in water-exporting regions, water-transmitting regions (through which water moves from the exporting to the importing regions), and in water-importing regions. By transferring water from a natural habitat for the purpose of benefitting a different region, could the policy itself become harmful? The policy was established to move water, and the original intention was appropriate, but there could be unforeseen and obstructive outcomes. Some of the outcomes result in immediate problems, such as perpetuating inequality through the act of displacing people close to a basin or in the path of pipeline or canal that is used for the purpose of transferring water. However, sometimes the damage takes a long time to surface or to be realized; for example, the selenium problem that occurred on the west side of the San Joaquin Valley that surfaced in 1985, 25–30 years after the federal and state water transfer projects (CVP and SWP, respectively) had begun operation.

We used information in the published literature on IBTs to assess their sustainability as a policy intervention aimed to ease water scarcity at both the local (intra-basin transfer) and regional (interbasin transfer) levels. Since very few quantitative cost benefit analyses are available for IBTs (we identified 21 reported IBTs based on quantitative cost-benefit analysis (CBA) that vary from each other to the extent that they cannot be compared), we applied QUAlitative Structural Approach for Ranking (QUASAR) to 121 studies of documented IBTs from around the world, using five attributes of impacts that in the literature were associated with the transfers. These attributes include social impacts (private impacts are included where applicable), including any negative and positive externalities that are found within the literature describing these IBTs.

The paper develops as follows: In Section 2 we highlight advantages and disadvantages (citing a handful of examples from the literature) of IBTs and methods used to assess the impacts of these transfers—both qualitative and quantitative. In Section 3 we lay out the analytical framework we used to analyze the overall impacts of the different IBTs in our sample. Section 4 presents the major features of the empirical methodology (our coded attributes) of the IBTs in our sample. Section 5 presents the results of our analysis. Section 6 discusses the issues we faced and addressed. Section 7 concludes, highlights policy implications, and discusses some of the caveats of the analysis.

2. Pros and cons of IBT: affected parties, interested parties, and benefits and losses[4]

Authors who have discussed the various economic and policy-related aspects of past IBTs use the rising demand for water around the world as the reason for transfers as early as 50 years ago [24].

IBTs are associated with both positive and negative impacts to water-exporting, water-transmitting, and water-importing regions. IBTs are associated with building reservoirs and dams. The World Commission on Dams [44] stated that the "unprecedented expansion" of dam building during the twentieth century clearly benefited many people globally. But, the positive impacts upon individuals and groups brought by these dams have been offset by negative social, economic, and environmental impacts, such as high numbers of displaced people (estimated to range from 40 to 80 million), lack of equity in the distribution of benefits, and negative impacts on ecological services—rivers, watersheds, and aquatic ecosystems [19].

IBTs are also associated with indirect costs in the form of political objection or persuasion of the population in the exporting and importing regions. For example, in 1992, Yemeni people living in Habir discovered that their region had been "proposed as the next source of water" for Ta'iz city; however, the people living in Habir had seen the impact that a water transfer had on the neighbouring valley of Al Haima, so they were determined to stop the transfer. Until 1995, they were able to postpone the project but, eventually, a financial understanding was agreed upon, and the villagers allowed construction to take place [25].

In some countries with very large land areas the inter-basin water transfers are on the agenda of policymakers for quite some time. Mahabaleshwara and Nagabhushan [31] review the challenges (engineering, political, and institutional) associated with several of the river inter-links that have been proposed and initiated to a certain extent.

Negative impacts, including those in the exporting regions and basins involve higher levels of aridity and increased levels of salinity, both of which damage the ecology of the exporting basins. Additional damages are associated with an increase in water consumption in the importing basins, and the possible spread of disease due to contamination of the water at the source or along the conveyance route. In addition, some effective alternative measures have been established for IBTs, such as improving efficient water use, investing in desalination technology, and rainwater harvesting practices" [51]. One of the major features of an IBT, which is commonly labelled as "positive," is the redistribution of water resources between regions. However, this could lead to inequity for the exporting basin and also the territories or areas between the exporting and importing basins, where the conveyance infrastructure is proposed to be constructed, showing that "IBTs are double-edged swords" [51]. These construction projects will most likely introduce long-term issues to the surrounding territories and to the ecological environment. Compared with water conservation measures [36], IBTs involve far more problems that could arise along a more distant horizon [51].

The environmental impacts of water transfers vary around the world. For example, in Bangladesh negative impacts on fish resulted from an IBT, and from an environmental justice perspective, displacement of people and loss of crops occurred [45]. In the Sibaral basin in Central Asia, negative environmental justice issues resulted because of the river reversal where Central Asia and Kazakhstan called for water within the Ob to be redirected south, where the water was actually "needed" [45]. Another example is the Snowy Mountains, which were met with adverse impacts because of the scheme that produces gigawatts of electricity for the surrounding region, and also because of poor natural resource management, leading to reduced flows below each diversion point [45].

Yevjevich [49] explains that while it is generally assumed that water users in the exporting region will lose future benefits of the water by allowing for that diversion, water users in the importing region will benefit from importing that diversion. This creates a winner vs. loser scenario, in which the source region loses for having a surplus of water, and the importing region is rewarded for having a deficit. However, it is not that simple. It needs to be assessed and, if possible, enumerated how much damage will occur in the region that receives the diverted water, and if any positive impacts could occur in the region from which the water is diverted. Diversions or transfers of water are multi-disciplinary problems with a physical aspect that is related to the geomorphology, water quality, and overall water resources in the exporting and importing regions. Hydraulic engineering assessments should determine how the water will actually be conveyed from point A to point B. For the sociologic aspects of a diversion or transfer, the components are "political, administrative, economic, ecological, environmental, and legal," because these components define how people and the environment will be *affected* by this transfer of water [49]. Inter-basin transfers "require joint planning" between the interconnected basins. In more complex cases, though, several basins become interconnected and need to cooperate in order to implement the transfer successfully. In extreme cases, all river basins and regions through basin or regional water transfers become interconnected, such as the National River Interlink Project in India [49].

Snaddon et al. [40] provide a qualitative accounting of the impacts of the 51 existing and 53 proposed IBTs in their study. While the impacts assessed are only described rather than measured, one can have a meaningful grasp of what constitutes the range of impacts of IBTs. Snaddon et al. [40] identified (but did not monetize or quantify) several types of impacts affecting part of the 104 IBT projects. Such impacts include positive and negative effects both in the exporting and in the importing regions. Certain IBTs could be affected by several of the following impacts: (a) effects on water quantity and flow patterns (9 IBTs); (b) effects on erosion and geomorphology of riverine systems (7 IBTs); (c) effects on groundwater resources (5 IBTs); (d) effects on water quality (15 IBTs); (e) effects on aquatic ecosystems (48 IBTs); (f) socio-economic effects (8 IBTs); and (g) cultural and aesthetic effects (5 IBTs).

3. Analytical framework

As we described earlier, IBTs are associated with positive and negative impacts in the exporting and importing regions, as well as in the transit regions that constitute the transfer infrastructure. Some of the impacts are direct and some are indirect, some are immediate and some are likely in the future. Howe and Easter [24] developed a set of two necessary conditions for economically efficient IBTs: (1) the additional net benefits realized in the importing and transit regions must be greater than the loss in benefits incurred by the exporting regions and other regions indirectly affected by the transfer, plus the additional costs associated with the conveyance infrastructure; and (2) the cost of the infrastructure for the transfer scheme, including the net opportunity cost of the water, must be smaller than the cost of the best alternative for supplying the same amount of water in the importing region.

These two conditions imply many difficulties in measurement, in identifying gaining and loosing parties, and in assigning values to direct and indirect positive and negative impacts. They also place difficulties on possible comparison among IBTs. These difficulties explain our observation that only few of the IBT-reporting studies include a benefit-cost analysis. Moreover, even the handful of IBT studies that include benefit-cost analysis cannot be compared, because they incorporate different assumptions, they use different horizons for the project analysis period, and they use different discount rates. The majority of the studies in our review provide only ordinary (dichotomous) measures of the impacts (benefits or costs). They indicate whether or not there is a negative impact, a positive impact, or no impact of certain attributes associated with the transfer, as was mentioned in the previous section. Another challenge in evaluating the IBT is the existence of impacts

[4] The literature included in this section is by no mean a representative sample of the IBTs around the world. Our aim in this selected previous work review is to provide an anecdotal flavor of the issues that could be faced by the different IBTs, and to show that the comparison between different IBTs is difficult, if not impossible.

(costs or benefits) that are difficult to quantify and to monetize. van den Bergh [46], and Rogers et al. [37] explain different approaches to a qualitative CBA, but they both focus on the difficulties associated with assigning values to qualitative data, whether it is in regard to identifying environmental costs and benefits associated with climate change policy, or the efforts associated with quantifying socioeconomic costs.

Due to the nature of the information we extracted from all reviewed IBT studies, and following the earlier discussion on the difficulties to compare extent of impacts within an IBT and across IBTs, we adopted and adapted the QUASAR method as explained in Galassi and Levarlet [18]. The approach applied in Galassi and Levarlet [18] allows to compare between plans and programs (P/Ps), measuring their ability to address environmental consequences of particular P/Ps. QUASAR makes it possible to quantify the effects using an a-priory determined scale of values, which makes the assessment of the effectiveness of the P/Ps reproducible and independent of the evaluating individual. While Galassi and Levarlet [18] applied an assessment scale ranging between −6 and +6, several works cited in Arvidsson [4] referred to the controversy in using ordinal scale measurements. The controversy arises from the unknown distance between ordinal values and the resulting mathematical limitations of the comparison.

In social life cycle assessments (LCA), the use of ordinal scoring scales has become the common practice. As summarized by Arvidsson [4] the common ordinal scales include, but are not limited to: (a) (0, 1, 3, 5, 7, 9) [23], (b) (low, medium, high, very high) [32], (c) (1, 2, 3, 4) [35]and (1, 2, 3, 4, 5, 6) [8]. Ordinal scale values are also transformed into integers at some point in the assessment (e.g., very high → 6). One more example, similar to our methodological ranking, was used in Fontes [17], where the ordinal scale (+2, + 1, 0, − 1, − 2) is used for scoring. The individual impact scores can then be aggregated by social groups of activities and then can be further weighted (to reflect social preferences) into aggregated scores by social, geographical, or size of the group overall score [4].

Our assessment model was developed as follows: Our literature review consisted of published titles that include “Inter- and Intra-basin Water Transfers.” During the review of the literature we identified impact attributes that were discussed by the authors of the IBTs reviewed. Each IBT reviewed was associated with up to N attributes (as will be explained in the next section). We found several analyses of the same IBT. Some of the analyses included subsets of the N attributes. Therefore, in these cases we combined the attributes from the various reports. We did not find different impacts (e.g., negative or positive effects) in the various publications addressing the same IBT). Because no quantitative measurement was provided, or even in the few that included benefit cost analyses, we just marked whether or not an attribute is mentioned as having a positive, negative, or neutral impact.

Let A_i be the impact of the water transfer on the sustainability of attribute i, $i = 1, \cdots, N$.

$$A_i = \begin{cases} -1 & \textit{if} \text{ the IBT has a negative effect} \\ 0 & \textit{if} \text{ the IBT has a neutral effect} \quad \text{for } i = 1, \cdots, N \\ +1 & \textit{if} \text{ the IBT has a positive effect} \end{cases}$$

Then the total net effect (*NE*) of the water transfer (or the composite impact) is

$$NE = \sum_{i=1}^{N} A_i$$

where NE could take a negative (integer) value of −1, a zero value, or a positive (integer) value of +1. Given the nature of the A_is we can expect that $-N \le NE \le +N$.

Assume N sustainability attributes that can be identified in relation to the intra- or inter-basin transfer. Some of these sustainability attributes could remain neutral as a result of the transfer, some could be affected negatively, and some could be affected positively. In each particular reported transfer study we could identify effects on all or a subset n of the N sustainability attributes, where $0 \le n \le N$. Therefore, where a given attribute was mentioned, but no particular cost or benefit was mentioned in the reported analysis of the transfer we assumed that its impact on that particular attribute is neutral (zero).

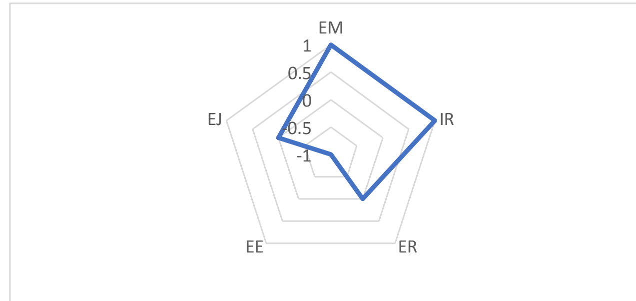

Fig. 1. Area graph representing the impact of five attributes of the Istranca and Konya plain projects in Turkey.

This QUASAR-adapted model is described as “Likert Scale-like” because it has assigned values of −1, 0, and 1 in order to value this qualitative data in a quasi-quantitative manner. A short definition of the Likert Scale for the purpose of this adapted methodology is that it is a symmetric scale, where “the position of neutrality” (which is typically represented within the scale as “don't know”) lies exactly in between the two extremes of strong disagreement to strong agreement. This method was chosen for the purpose of our analysis because of its ability to cater to either extreme, or remain conservative (close to center - the position of neutrality). The attribute values were assigned based on how a reviewed study described an attribute related to a transfer: whether the transfer was “damaging” or “beneficial” for humans or the environment was used as the basis of coding each respective attribute [27,42].

The total net impact of an IBT can also be presented using an area graph [14,1] as is depicted in Figs. 1 and 2 for two different IBTs with relatively overall high impacts and overall low impacts in our sample.

4. Empirical methodology

The literature on IBT doesn’t provide too many consistent sources that can serve as basis for the development of our empirical methodology. Das [12] analyzes the environmental and ecological impacts of major inter-basin water transfers in Canada, using criteria such as policy-making procedures, water laws, as well as other decision-making criteria. The objective was to explain the procedures leading to the transfers rather than the impact of the transfers. Zhuang [51] reviews 10 IBT cases from around the world to extract criteria by which environmental impacts can be assessed. Using the 10 IBT examples the author described the positive and negative impacts on the exporting, the transmitting, and the importing regions. However, that specific approach cannot be generalized and adopted elsewhere. Kibiiy and Ndambuki [28] introduce, what they coin ‘new criteria’ to justify inter-

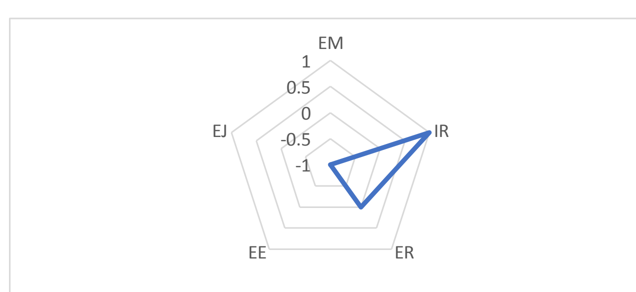

Fig. 2. Area graph representing the impact of five attributes of the Kizilirma Project, Melen Project and Ankara in Turkey.

basin water transfers. Their approach resembles an ex-ante analysis of water transfers (rather an ex-post assessment that we attempt in our analysis). Their three criteria (justification of the transfer, demonstration that the negative impacts are minimized, and demonstration that the positive impact are maximized) are applied to a proposed basin transfer in Kenya. Finally, the work by Gupta and van der Zaag [22], which was, to some extent, the departing point for the work by Kibiiy and Ndambuki [28] which uses criteria to assess whether or not an IBT can be justified. They review (a) criteria examined in policy literature aiming at the nature of the process leading to the involvement of the local parties in the design of the transfer, (b) criteria used in legal documents, addressing mainly rights of local communities and equity of the transfer, (c) criteria used in scientific literature, which examine ecological integrity, and economic efficiency. They suggested 5 criteria for justification of an IBT: (1) water scarcity in the importing region cannot be satisfied by any other means but IBT, (2) loss of water in the exporting region must be compensated, (3) no sustainable environmental damages in either the exporting, importing, or transmitting regions, (4) socio-cultural disruptions in either region should be minimized, and (5) the entire benefits from the IBT should be equitably allocated among all regions involved. Gupta and van der Zaag [22] applied their criteria to the “River Linking Program” in India.

Another set of criteria applied to yet ex-ante interbasin transfers analyses in Iran [3]; based on Cox [10] which also included economic, environmental and sociocultural criterions. Having some similarities with criteria used by others, they include (1) whether or not IBT is the last possible alternative after other alternatives have been exhausted in the importing region, (2) physical impact on the exporting region must be minimal, unless the exporting region is compensated by the importing region (through side-payment), (3) no substantial environmental quality degradation within the exporting or importing regions (we would also add the transmitting region), unless compensation to offset environmental damage is provided, (4) no substantial sociocultural disruption in the exporting or importing regions (we would also add the transmitting region), unless compensation to offset potential sociocultural losses is provided, and finally (5) the net benefits from the transfer have to be shared equitably between the exporting and importing regions.

While the objectives and scale of the analysis in the several reviewed studies above, as well as the focus on ex-ante analysis is not similar to what we attempt of doing, there are several similarities in the criteria suggested for justification of the IBT [3,22,28] and the impacts of IBTs on overall water efficiency, economic and agricultural production, environmental sustainability, and sociocultural justice. One particular point to be highlighted is that in such complicated water projects as IBTs, ex-ante results may not hold for the ex-post period given the many uncertainties and interrupting events that may change the values calculated in the ex-ante analysis. This is a major aspect that differentiate our work from several of the ones we discussed in this section, and thus our methodology is based on the empirical investigation of the IBT cases, as is explained below.

During our review of the identified IBT cases in the literature we marked the various impacts identified by the authors of each IBT analysis/description. Impacts of IBTs were divided into five categories/themes: (1) efficiency management effect (EM), measuring the overall efficiency associated with the management of the basin water; (2) irrigation outcome effect (IR), measuring the effects associated with irrigation projects which were the destination of the transferred water in many cases; (3) environmental rehabilitation effect (ER), measuring the effects of transfers aimed to move water in order to support ecosystems in the receiving regions; (4) environmental/ecological effect (EE), measuring the pervasive effects of the transfer on the environment/ecosystems; and (5) environmental justice/equity effect (EJ), measuring the social and cultural effects of the transfer on indigenous and poor communities in the exporting, transmitting, and importing regions.[5]

Efficiency management effect indicates that an IBT uses/allocates the transferred water for higher or lower value than was originally used. Irrigation outcome effect indicates that the transfer (in many cases focusing on an irrigation project) has a significant effect (negative or positive) on crop production. Environmental rehabilitation effect indicates whether the IBT is either supporting environmental flows, or promoting the use of water transfers to benefit the environment. Environmental/ecological effects indicated whether or not the IBT had negative or positive externalities affecting the environment in the exporting, transmitting, or importing regions. Environmental justice effect indicates whether the IBT created inequitable distribution of benefits or costs, or even deprives local communities from their existing rights.

4.1. Empirical specifications

The scoring codes were assigned, albeit with some subjectivity by each author separately. In case of disagreement, the authors discussed and reached an agreement (there have been 17 disagreements only, mainly across the values of +1 and 0). Values were assigned upon reading of the IBT analyses and identifying prevalence of each of the attributes. We have not identified an ordinal scale for the severity or for the level of benefits associated with each attribute, but rather whether or not a particular attribute was mentioned as effect (positive, neutral, or negative) on the IBT. We also did not distinguish between the effects of the attributes and assigned all the same range of impacts (see Annex 1 for scoring on all 121 IBTs and attribute ranking).

Scores for each attribute were −1, 0, or +1; for example, if a transfer was categorized as being solely associated with positive environmental effects, then its summed score would be set at +1. If an IBT was categorised as being about sustainable management (EE or ER along with EM) then its impact could be assigned on a spectrum, but the sum would not exceed a value of 2 or −2. While this IBT could be more focused on sustainability than management, it could be qualitatively assigned as a −1 for environmental rehabilitation, and a +1 for efficient management, leading to a total aggregated score of 0, which is referred to as a neutral impact transfer within this analysis.

5. Analysis and results

We conduct various distributional analyses of the attribute scores of the 121 IBTs. The results are presented in Tables 1 and 2 below. Table 1 presents the frequency distribution of the five attributes over the 121 IBTs.

Table 1 suggests that efficiency management effects (EM) and environmental/ecological effects (EE) were the majority of detected effects in the reported IBTs. The table also suggests that negative effects from IBTs have been associated with efficiency management (32.0%), irrigation outcomes effects (51.5%), and ecological effects (92.4%).

The distribution of the aggregated attribute score per IBT helps answer the question of whether or not IBTs are a sustainable policy. Table 2 presents the distribution of the aggregated attributes over the sample of the 121 IBTs. The table records the range of the overall effects, ranging between +4 and −4 and their frequencies

As seen in Table 2 (and in Fig. 3), the number of IBTs with a total negative attribute value is 58 (48% of the sample). The number of IBTs with no effect, either negative or positive is 26 (21.5% of the sample), leaving the number of IBTs with positive effects at 37 (30.5% of the sample). This overall finding leaves us with a major policy question

[5] We should emphasize that the five attributes are not mutually exclusive. This is especially important to mention in the case of ER, EE, and EJ, all somehow related to environmental aspects. However, they do not overlap, as mistakenly can be thought of, but rather, each of them relates to specific and particular effects that have been seen separately in water-related negative externalities.

Table 1
Frequency distribution of IBT attributes in the sample.

Attribute	EM	IR	ER	EE	EJ
Number of IBTs with that attribute (positive, neutral, negative)	75	33	22	66	30
Percentage of negative attribute	32.0	51.5	31.8	92.4	70.0

Note: efficiency management effect (EM); irrigation outcome effect (IR); environmental rehabilitation effect (ER); environmental/ecological effect (EE); environmental justice/equity effect (EJ).

Table 2
Distribution of IBT overall effects.

Attribute aggregate score	4	3	2	1	0	−1	−2	−3	−4
Number of IBTs with score	0	4	10	23	26	32	21	4	1
Frequencies (%)	0	3.3	8.3	19.0	21.5	26.4	17.4	3.3	0.8

regarding the sustainability of IBTs that have been documented and used in this paper.

We found a relatively high level of variation for each of the five attributes across the sample projects (Table 3). Leading in their level of variation and measured as the coefficient of variation are the irrigation outcome effect (1600%) and the environmental rehabilitation effect (343%). Lowest variability in the attribute scores is seen in the case of the environmental or ecological effect (51%). All these values indicate a wide range of effects across geographical locations.

We found a relatively reasonable level of variability (SD) of the aggregate attribute scores across the 121 IBTs we analyzed. Results in Table 4 suggest that 43 percent of the IBT scores are associated with SD values of 0.4–0.5 while only 9 percent of the IBTs show SD values ranging between 0.8 and 1.0. Another interesting observation is that of the 27 IBTs with a mean impact score of 0 we observe 3 IBTs in the highest variability level (SD of 1.0) and 24 IBTs with a lower variability range of 0.6–0.8. The latter observations (range of SDs of zero between attributes suggest that most of our neutral-scored overall impacts are the result of both positive and negative effects in all five attributes rather than a low or no impact.

Table 3
Variation in the scored impacts across the five IBT attributes.

Item	*EM*	*IR*	*ER*	*EE*	*EJ*
Mean	0.506	−0.061	0.273	−0.879	−0.419
Standard Deviation (SD)	0.828	0.998	0.935	0.448	0.886
Coefficient of Variation (CV)	1.634	−16.468	3.428	−0.509	−2.113

Table 4
Variation (SD) in scored impacts across the 121 IBTs.

Range of SD	0.4–0.5	0.5–0.6	0.6–0.8	0.8–1.0	Total
Number of IBTs	52	34	24	11	121
% of IBTs	43	28	20	9	100

Notes: (1) See Annex 1 for individual IBT scores' SDs; (2) due to the fact that some IBT mean scores have a value of 0 we are unable to calculate a meaningful Coefficient of Variation.

6. Discussion

Facing various water-scarcity levels and their impacts, policymakers consider intra- and inter-basin transfers among other policy interventions, such as pricing of water and local supply amendment projects. While many of the other policy interventions have been evaluated for their effectiveness and efficiency, IBTs, which are much more complicated interventions have not (at least in the global context), mainly due to the difficulties to harmonize the analyses across all cases and to find appropriate economic indicators for all possible attributes/impact of the transfers. In recognition of such difficult conditions for a global analysis, and with the growing importance of comparing across the many IBTs reported in the literature, we apply a simple, but useful, approach that allows for the dichotomous identification of impacts associated with the various attributes of the transfers.

The distributions of the five attributes of the IBT effects that we were able to identify in the 121 IBTs show that several attributes are harder to obtain in the positive range than others. Environmental or ecological effects (EE), irrigation outcome effects (IR), and environmental justice/equity effects (EJ) are associated with negative means, indicating the difficulty to obtain positive effects of these attributes in a

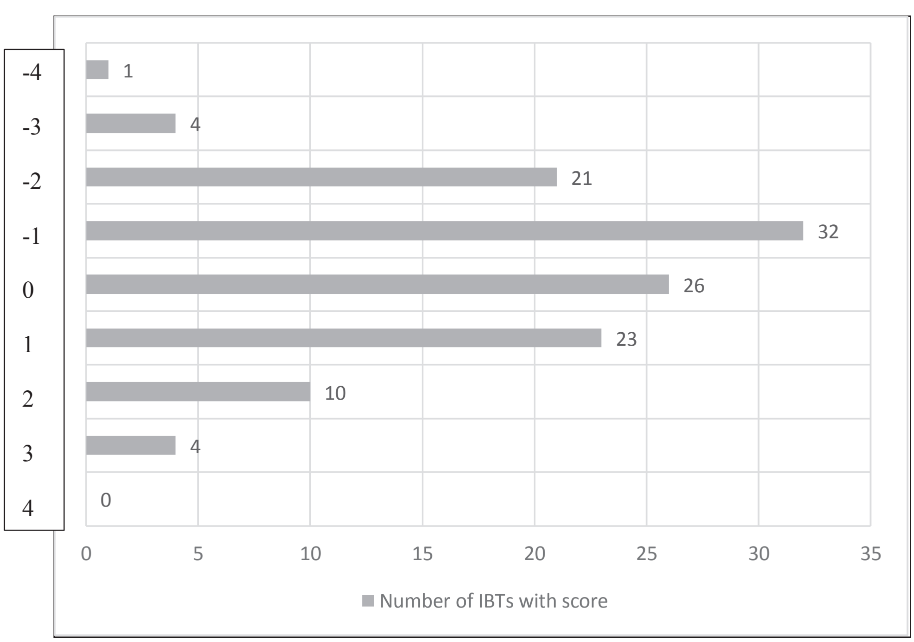

Fig. 3. Distribution of IBT overall effects.

water transfer. All other attributes (EM and ER) are associated with a small positive effect.

Nearly half of the transfers that target irrigation projects (IR) were found to be associated with negative impacts, which is bothersome due to the fact that irrigation water captures 60–90% of the available water in the world. Therefore, the irrigation component might have a much larger negative effect if the impact can be calculated using more specific impact analysis methods. IBTs that include efficiency management effects (EM) and environmental rehabilitation effects (ER) have scored a lower percentage of negative effects in total (around one-third of such IBTs had negative effects). Overall, it could be seen that there is a negative share for the assigned codes (if a zero effect is not included within the positive effects) with nearly 70% of the IBTs with an overall negative score.

Another observation that characterizes the IBTs in our sample is the relatively high level of variation of each of the five attributes across the sample projects (Table 3). This observation may indicate a need for a more comprehensive global analysis of IBTs, as we will allude to in the conclusion section below. We also observed (Table 4) that overall-scored impacts of 0 in 27/121 IBTs are a reflection of positive (+1) and negative (−1) impacts rather than no impact (0).

7. Conclusion, policy implications, and caveats

Regional water transfers, whether inter- or intra-basin, deal with or combat scarcity by acting as a means for protecting the water security within several basins. Since there is a problem with equitable and efficient allotments, there inevitably will be an inequitable distribution of water externalities. In some regions environmental issues, such as land subsidence, exist in exporting regions, or the exporting or importing regions may be at risk of losing a species. Would it be better to stop using transfers for cases such as these? A solution that has been called on in the past is to demand comprehensive CBAs, and more detailed information on places that have either done IBT "right" or know how to ameliorate these wrong outcomes based on past failures elsewhere. From the sample of 121 IBTs that we were able to review, we found that only 21 are based on CBA, but they differ in many of the assumptions used to the extent that they cannot be compared. Therefore, our recommendation is to establish an agreed-upon procedure for CBA of IBTs that will allow not only individual analyses, but also comparisons across IBTs and lessons learned. A possible departure point is the framework suggested by Howe and Easter [24].

7.1. Policy recommendations

Several policy implications can be generated from our analysis. A suggested policy direction is to pursue the development of more sustainable technology. We offer several policy approaches for consideration in order to reduce possible negative effects of the IBTs. While the first three approaches assume that IBT of water will be reduced and drastically changed, the last two approaches assume that IBT of water will continue unchanged.

1. Movement of urban centers to the vicinity of the basin from which they have historically received their IBT water. This solution is modified from the common public transport utilizing utopia described by many public policy experts. If it is socially unsustainable to move the water supply, it could be more sustainable and beneficial to the environment to have the demand centered around and adjacent to the water supply source. Of course, this suggested solution may bring up new issues of both private and social benefits, and external costs, but is has to be addressed as part of a possible solution.
2. Sharing water rights between humans and the environment. This was done in Australia in response to an overdraft of water rights for water originating within the Murray-Darling Basin. The government pledged $13 billion to buy back water rights for the sake of the environment, and used subsidies to incentivize farmers (although found not to be very effective) to use more sustainable technology and practices to extract and use less water from the basin [11]. The Australian response to drought and unsustainable conditions could be used as a basis that can be adapted for use at a localized level in counties and cities before being used on a state or national scale. We are aware of the ongoing public discourse in Australia and around the world [21,11] regarding the effectiveness of the Australian federal government buy-back and irrigation equipment subsidy programs and its perverse outcomes manifested in movements of significant amounts of water across parts of the basin. Re-examination and re-adjustment of this policy could be relevant for other geographical locations.
3. Smart water markets, water banks, environmental flow allocations for the betterment of the environment and the food web, payment for environmental services to offset environmental damages. These markets, banks, and allocations, using local water sources in the importing regions, should be considered as opposed to a heavy reliance on transfers of water from another basin or region to offset water deficits in the local region. This solution would create water markets in which people are incentivized to become more efficient with their water use because they can bank excess water, or sell excess water to those living in their local area. This would allow for more water independence, in which people rather than utilities decide how they want to use or if they want to conserve their water [7,34].
4. Institutions and regulations to promote cooperation. There should be more policy solutions, such as the 2014 Sustainable Groundwater Management Act (SGMA) in California and the resulting groundwater sustainability agencies (GSAs) which were created to support surface water and groundwater transfers or water banks to increase efficiency of water use. GSAs could promote the use of recycled water for the sake of groundwater recharge, and for water independence to lessen demand for water delivered through IBTs in the importing regions. If there were localized transfer agencies (while this is considered to be more regulation), there could be more accountability for IBTs or water rights holders, and a step towards actually placing a number on the real costs and benefits of water transfer for the exporting and importing basins, and how the environment is affected by the conveyance between these two points.
5. Assigning a value to nature (and water) and considering it in the evaluation of the transfer. Sun et al. [43] attempted at valuing water, using three methods to examine the payment for ecosystem services by calculating the willingness (and ability) to pay for water and environmental conservation at both ends of the transfer. In particular, the conservation cost method (CCM), the market value method (MVM), and the payment ability method (PAM).

7.2. Implementation plan of different types of transfers

Involuntary: government-enacting top-down implementation due to a "state of emergency." Many transfers within the United Arab Emirates (UAE)/Gulf Cooperation Council (GCC) could be defined as being involuntary, simply because there are not a lot of other options to be considered, other than exploration of desalination, or informal talks about moving urban concentrations from one water-impoverished region to another.

Voluntary or cooperative: meeting with the people and conducting environmental studies to determine the impact of the policy on all of the affected groups. This may take longer and can be more complicated, but it would be more sustainable. However, it is also the most unrealistic.

Permanent: bureaucracy entrenching a transfer so that it cannot be undone. The majority of these transfers appear to be nested within this category; specifically, the sources in the literature discussing the South-North Water Transfer Project in China [5].

Temporary: transferring water from one territory to another for a fixed period of time. One specific transfer described by Zeidan [50] occurring within the Nile Basin seems to encompass this category. The transfer is based on a water compact attempting to be reached between eight countries, but Egypt and Sudan refuse to reallocate their water rights, so the other six countries will, in effect, have to suffer because a mechanism for water rights re-assignments in this region between these riparian countries doesn't exist. But its introduction will increase water transfers among riparian states [15].

Possible unseen problems result when private/economic or monetary interests that people view as important supersede environmental ones. For example, the transfers from the Tuolumne River to the San Francisco Public Utilities Commission (SFPUC) could be a viewed as a positive for urban society by one source, but seen as a scourge on the environment by another source. Depending on the values placed on San Francisco and its inhabitants, it may be seen as more important to supply affordable, clean water to humans than it is to preserve the Tuolumne River by withdrawing flows from Don Pedro Reservoir.

Considering that water transfers can be assigned to these specific categories is where difficulties lies for territories to follow new policy directions. These difficulties include transboundary and nature issues not having well defined costs and benefits. Difficulties also arose during data analysis with regard to the way the quantitative sources in the literature discussed water transfers as opposed to how qualitative sources in the literature discussed water transfers. People from different disciplines and organizations from varying backgrounds could view a water transfer with completely differing views.

7.3. Caveats

The approach and data we used might be subject to several caveats that were discussed earlier in the paper and are summarized below.

A lack of information on the total number of IBTs doesn't allow us to assess whether or not our sample is representative. However, from comparing our sample to earlier studies we can argue that our sample is equal or larger than those listed (not analyzed) in previous publications [40,22,39]. Similar to the issue of a lack of information on the total number of IBTs occurring in the world, there is a lack of diversity in disciplines that analyze the effects of IBTs within the literature. The assumptions used in the various studies we collected could be biased somehow toward the beliefs of the authors. There is no feasible way we could control for such possible biases.

And finally, by using the metric of −1, 0, 1 to measure the effects of each of the five attributes, we assigned them of equal importance across the IBTs that we analyzed. This assignment may likely not be appropriate because the exporting, transmitting, and importing regions of an IBT are subject to different physical conditions that may make each of them sensitive in different manners to the different attributes.

These caveats, however, should not prevent scholars from continuing to research and improve the analyses that assess the importance and risks of IBTs as a policy intervention for securing water in regions with high levels of scarcity. As climates change, populations grow, and water use intensifies, we can expect only increases in regional water scarcities and, thus, realize the importance and interest of intra- and inter-basin transfers (IBTs) of water.

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Annex 1: Impacts of attributes by IBTs.

Basin or Territory	Individual Attribute Score					Aggregate Score	SD of Individual Attributes
	EM	IR	ER	EE	EJ		
Ayun	1		1	1		3	0.548
Eastern Nile	1		1		1	3	0.548
LHWP – Katse Dam			1	1	−1	1	0.837
LHWP –				−1		−1	0.447
SNWTP –	1			−1		0	0.707
SNWTP –					−1	−1	0.500
SNWTP –	1				−1	0	0.707
SNWTP –			−1	−1		−2	0.548
SNWTP - basins of the Yellow, Hui and Hai Rivers	1				1	2	0.548
Godavari Krishna Link	1				−1	0	0.707
CVP – Kesterson,			−1	−1		−2	0.548
CVP - Don Pedro	−1					−1	0.447
CVP - Don Pedro	1			−1		0	0.707
Sao Francisco	1				−1	0	0.707
Sao Francisco	1				−1	0	0.707
Jaguaribe	1					1	0.447
Piedmont Triad, NC	−1					−1	0.447
CA, WY	1	1				2	0.548
CA	1					1	0.447
Kern	1	−1	−1	−1		−2	0.894
South Korea – Han River	1				1	2	0.548
Aral Sea				−1	−1	−2	0.548
Aral Sea				−1	−1	−2	0.548
Aral Sea		−1		−1		−2	0.548
Aral Sea		−1	1		−1	−1	0.837
Aral Sea		−1		−1		−2	0.548
Aral Sea				−1		−1	0.447
Aral Sea		−1			−1	−2	0.548

Australia			−1	−1		−2	0.548
Australia	1	−1				0	0.707
Southern Australia		1	1		1	3	0.548
Australia				−1		−1	0.447
Australia	1			−1		0	0.707
CVP	1	−1				0	0.707
CVP		−1				−1	0.447
CVP		−1				−1	0.447
SWP	1				−1	0	0.707
SWP	0	1				1	0.447
SWP	1			−1		0	0.707
Mono Lake				−1		−1	0.447
Mono Lake	1			−1		0	0.707
Great Lakes	−1			−1		−2	0.548
Great Lakes	1			−1		0	0.707
Upper Great Lakes				−1		−1	0.447
Great Lakes	1					1	0.447
Great Lakes				−1		−1	0.447
Great Lakes				−1		−1	0.447
Salton Sea	−1	−1		−1		−3	0.548
Salton Sea		−1		−1		−2	0.548
Salton Sea				−1		−1	0.447
Salton Sea				−1		−1	0.447
Georgia (state)	0		1		−1	0	0.707
Georgia (state)				−1		−1	0.447
Georgia (state)				−1		−1	0.447
New Mexico	1					1	0.447
New Mexico		−1		−1		−2	0.548
New Mexico	1			−1		0	0.707
Western U.S.	−1			−1		−2	0.548
Western U.S.				−1		−1	0.447
Western U.S.	1					1	0.447
Western U.S.			−1	−1		−2	0.548
San Joaquin Valley	1					1	0.447
San Joaquin Valley		1	−1	−1		−2	0.837
Tibetan Plateau				−1		−1	0.447
Tibetan Plateau				−1		−1	0.447
India				−1	−1	−2	0.548
India	1					1	0.447
India	1				−1	0	0.707
India	1	1				2	0.548
India	0			−1	−1	−2	0.548
India		1			1	2	0.548
India – Sardar Sarovar Project (River Narmada)	−1	1	1		−1	−2	1.000
Southern Africa				−1		−1	0.447
Southern Africa				−1		−1	0.447
Southern Africa	1			−1		0	0.707
Southern Africa			1			1	0.447
Southern Africa				−1		−1	0.447
Africa	1					1	0.447
Africa	1					1	0.447
Nile Basin	−1			−1	−1	−3	0.548
Tuolumne	−1					−1	0.447
Tuolumne			−1	−1		−2	0.548
Tuolumne	1					1	0.447
Tuolumne		−1	1	1		2	0.837
Owens Lake	1					1	0.447
Urban use	1					1	0.447
UK	1					1	0.447
UK – Great Ouse				−1		−1	0.447
UK – River Wear			1	−1		0	0.707
UK	1					1	0.447
Spain – Iberian Peninsula	0	1		−1		0	0.707
Spain – Ebro	−1	−1				−1	0.548
Spain – Ebro	1	1				2	0.548
Spain – Ebro	−1					−1	0.447
Iran	1			−1		0	0.707
Iran	1					1	0.447
Iran	1					1	0.447
Iran	1					1	0.447
Iran – Lake Urmia	1			−1		0	0.707
UAE	1			−1		0	0.707
GCC	1					1	0.447
GCC	−1			−1		−2	0.548
UAE	−1	1		−1		−2	0.837
Turkey - Istranca and Konya Plain projects	1	1	0	−1	0	1	0.837
Turkey – Kizilirma Project, Melen Project and Ankara	−1	−1	0	−1	−1	−4	0.447
Turkey – Southeastern Anatolia Project (GAP)	1	1				2	0.548
Italy	1	−1			1	2	0.837
Italy – Verva, Viola and lake Cancano	1			−1		0	0.707

Italy	1			−1		0	0.707
Italy	0	1				1	0.447
China	−1				0	−1	0.447
China				−1		−1	0.447
China	1	1				2	0.548
China	1	1		−1	−1	0	1.000
China				−1		−1	0.447
China	1		1			2	0.548
China	−1			−1	−1	−3	0.548
All-American Canal				−1		−1	0.447
All-American Canal					−1	−1	0.447
South Korea – Nakdong River	1	0	1	0	1	3	0.548
Red Sea/Jordan River Basin	−1	−1	1	0	1	0	1.000

Note: Explanation of the ranking for each attribute and basin can be provided from the corresponding author upon request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wasec.2019.100058.

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