

THE ROLE OF GROUNDWATER IN WATER ALLOCATION ALONG THE JORDAN RIVER BASIN

ROLA QUBA'A, MUTASEM EL-FADEL, IBRAHIM ALAMEDDINE & MAJDI ABOU NAJM
Department of Civil & Environmental Engineering, Faculty of Engineering & Architecture,
American University of Beirut, Lebanon

ABSTRACT

Water allocation along transboundary rivers invariably ignores the contribution of groundwater in the allocation process of shared water resources. This paper presents a first effort at examining the impact of groundwater on water allocation along the Jordan River Basin (JRB). The sensitivity of allocation is quantified through the assessment of scenarios that use weight factors commonly advocated towards equitable water allocation. In the absence of established quantification of groundwater resources, the study derived estimates groundwater safe yield within the basin. It then attempted to quantify international water law factors to evaluate reasonable shares for the basin's riparian countries by accounting for both surface and ground water resources. While existing water allocation patterns in the basin are still skewed compared to allocations based on international water law, consideration of groundwater usage is perceived to provide more realistic presentation of water quantities available for integrated river basin management as an ultimate goal of potential water agreements. We argue that relying on surface water abstractions only can bias perceived inequities by riparians and that consideration that both ground and surface water abstractions provide a more realistic basis. Agreements over transboundary water necessitate the improvement of groundwater characterization and the development of a clear understanding of this resource including potential lateral flows and interconnectedness between aquifers within the basin.

Keywords: transboundary water, groundwater resources, Jordan river.

1 INTRODUCTION

Worldwide, there are 263 transboundary river and lake basins accounting for around 60% of global freshwater [1]. Of those, around 60% lack any type of cooperative management framework [2]. In this context, the management of transboundary rivers is often complex due to disagreements over water allocations, water flows, riparian's contribution to that flow, historic uses, and future demands associated with social, ecological, and economic needs of each riparian [3]. One approach for defining transboundary water rights is by relying on criteria advocated in international water laws (Table 1) that regulate the use of transboundary water under the principle of reasonable and equitable sharing among riparians [4].

While the criteria apply equally to groundwater aquifers that connect hydrologically to surface water [5], groundwater has often been neglected in water allocation schemes. In this context, the Jordan River Basin (JRB), whose riparians include Israel, Jordan, Lebanon, Palestinian Authority, and Syria, represents a case where historically several water allocation plans were proposed, towards realizing a formal agreement over the utilization of its water resources. Yet, these plans considered only surface water resources and targeted mostly agricultural development [6]. More recent JRB related studies that examined water allocation based on international water law criteria (Table 1) and integrated water resources management also considered only surface water [5], [7]–[10]. This approach may result in distortions in water allocation and a potential for perceived inequities amongst riparians. In reality, groundwater resources within the basin are believed to play a critical yet unexplored role [11]. Hence, this study examines for the first time the undisclosed influence of groundwater resources on water allocation within the JRB and develops a water allocation



Table 1: International law criteria for water sharing [7], [8].

Criteria	Definition
F1	Basin geography including the extent of the drainage area in the territory of each riparian.
F2	Hydrology of the basin, including in particular the contribution of water by each riparian.
F3	Climate affecting the basin.
F4	Existing and potential utilization of the waters of the basin.
F5	Economic needs of each riparian.
F6	Social needs of each riparian.
F7	Population dependent on the waters of the basin in each basin state.
F8	Costs of alternative means of satisfying the water needs of riparians.
F9	Availability of other water resources in the basin.
F10	Degree to which the needs of a riparian may be satisfied without causing appreciable harm and substantial injury to a co-riparian.

scheme using international water law criteria coupled with a sensitivity analysis reflecting riparians reported perspectives on water allocation. The study outlines the approach adopted for estimating the groundwater resources and quantifying the international water law factors under two conditions: 1) accounting for surface water only, and 2) accounting for both surface and groundwater resources. A scenario analysis was conducted by varying factors' weights to define water allocation schemes. The results are then discussed in terms of significant criteria for enhancing allocation shares for each riparian, and evaluating the impact of accounting for groundwater resources on the allocation.

2 METHODOLOGY

2.1 JRB groundwater resources

In the absence of established quantification of groundwater resources for the JRB, the study presents a first attempt at deriving an estimate of available groundwater safe yields based on literature reported information (Fig. 1 and Table 2). For this purpose, several major assumptions were adopted: 1) aquifers are disconnected to eliminate the effect of lateral flows and considering no groundwater is crossing political borders; 2) the groundwater safe yield considered as part of the JRB mimics the percentage of an aquifer's surface catchment area falling within the basin's boundaries. This implies that the proportion of an aquifer's safe yield belonging to the basin is assumed to be proportional to the percentage of the aquifer's surface catchment area available within the basin's boundaries. As such, aquifers within the basin's boundaries were identified along with their reported annual safe yields. The percentage of the surface catchment area of each aquifer was then estimated using GIS delineated catchment boundaries (Fig. 1). The groundwater safe yield of the basin is then estimated by summing the product of each aquifer safe yield by the percentage of the aquifer's catchment area lying within the basin's boundaries.

This approach is associated with several limitations. First, interconnectedness may exist between aquifers and the approach cannot differentiate between water from direct recharge over an aquifer's surface catchment area or from lateral flows through other aquifers within or outside the basin. Second, groundwater safe yield proportion of the basin is estimated by area proportionality only, not by other criteria like population within the aquifer catchment. Third, part of the safe yield within an aquifer does not necessarily mimic the aquifer's surface area. Though ascertainment of the source of water flows and the interconnectedness of aquifers is imperative, the adopted assumptions allow for having a preliminary estimate that

Table 2: Groundwater resources in the Jordan River Basin.

Groundwater Aquifer	Reported Total Safe Yield (MCM/year)	Average	Percent of Surface Area within JRB ^a (%)				
			Israel	Jordan	Lebanon	PA	Syria*
Lebanon's groundwater from Hasbani catchment	250-350 ^b	65 ^c	-	-	100	-	-
Tiberias	62 ^a	-	51.8	6.2	-	1	28.5
Western Galilee	117 ^d	-	3.5	-	-	-	-
Northeastern Mountain Aquifer	131-145 ^e	135-187 ^f	153 ^{f, g}	134 ^d	146.5	29.5	-
Eastern Mountain Aquifer	125-172 ^e	125-197 ^f	134 ^{f, g}	174 ^d	154.4	44.8	-
Yarmouk ^h	~200 ⁱ	-	-	22.8	-	-	70.5
Jordan valley floor	21 ^j	-	6.1	61.5	-	32	-
Jordan side wadis	15 ^j	-	-	96.5	-	-	-
Amman-Zarqa	87.5 ^j	-	-	56.3	-	-	-
Dead Sea	57 ^j	-	-	2.2	-	1.3	-
Azraq	24 ^j	-	-	0.3	-	-	-
Total groundwater safe yield within the JRB boundaries by riparian country (MCM/year)			43.1	126.0	65.0	120.8	158.7
							513.6

^a [12]; ^b [11]; ^c [11][13]; ^d The presented natural recharge rates are for 1993-2009 [14]; ^e [15]; ^f [16]; ^g Average groundwater basins recharge for the hydrological year 2010/2011

^j [16]; Yarmouk area within Jordan is 1,426 km² [17]; Yarmouk basin natural recharge is ~200 MCM/year (~40 MCM/year in Jordan and ~160 MCM/year in Syria) [18]; [19].

*Includes the estimated groundwater safe yield of the Golan Heights since the United Nations recognizes the Golan Heights as Syrian land that are occupied.



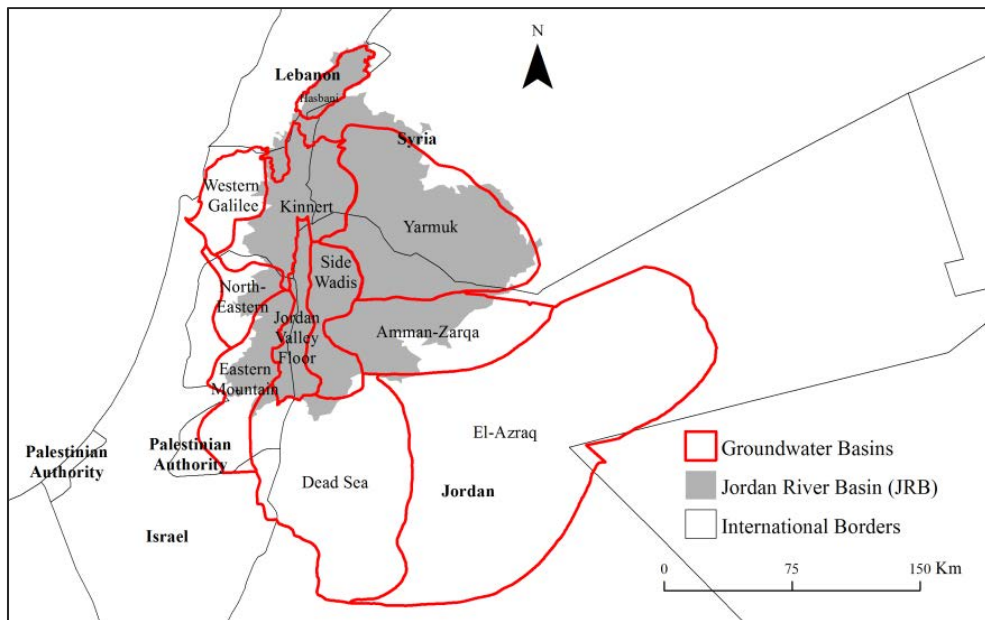


Figure 1: Groundwater basins within the JRB [12].

could be indicative of the significance of groundwater safe yield within the basin given the available information.

2.2 Quantification of International water law factors

The International water law factors were used to explore several scenarios whereby the factors were quantified (Table 3) in an effort to define water allocation schemes for the basin using two approaches: 1) considering only surface water resources; and 2) accounting for both surface and ground water resources. Adopting these two approaches influences the quantification of water flow (F2) and existing water utilization (F4). As such, these two factors were quantified twice. Once as F2(a) and F4(a) where water flows and utilization considered only surface water resources, and the second time as F2(b) and F4(b) which are quantified based on groundwater resources estimate and utilization. For the first approach of allocation based on surface water resources, the F2(a) and F4(a) were used. For the second approach, the sum of F2(a & b) and the sum of F4(a & b) were used.

2.3 Derivation of country scores for quantified criteria

For each factor under the two approaches of water allocation, country scores were derived as a percentage contribution to each riparian country, as expressed in eqn (1).

$$F_{i,j} = \frac{X_{i,j}}{(\sum_{i=1}^n X_{i,j})} * 100, \quad (1)$$

where i = riparian country (from 1 to $n=5$); j = number of the allocation factor (from 1 to $m=10$); $F_{i,j}$ = factor quantification score presented as the normalized score assigned to

riparian i with respect to factor j (%); and $X_{i,j}$ = value assigned to the i^{th} country with respect to the j^{th} factor.

The allocation factors were considered together as a whole and the weights assigned to each factor were based on their perceived relative importance in comparison to other factors. Initially, equal weights were assumed, suggesting no bias to any factor. Then, the weights were based on the average weights assigned by 90 international water experts (scenario 2), including representatives from the five riparian countries [9]. Given the likelihood that riparians will not agree on a common set of weights, 12 scenarios were tested, assuming different weighing structures. These “what if” scenarios start with the adoption of equal weights to all factors, followed with assigning higher weights to certain factors favoured by each riparian to shed light on the minimum and maximum allocation for all riparians from their perspective under various scenarios. This approach reflects also a one-factor-at-a-time (OFAT) sensitivity analysis to quantify the impact of each factor on the allocation scheme. A weight of 0.3 was assigned to a single factor (in an attempt to magnify its relative importance) and the remaining weight of 0.7 was divided equally amongst the remaining nine factors (scenarios 3–12). Changes in water allocation due to the variation in the weighing factors were then quantified. The overall allocation score for each riparian was calculated using eqn (2).

$$S_i = \frac{(\sum_{j=1}^m F_{i,j} * W_j)}{(\sum_{i=1}^n \sum_{j=1}^m F_{i,j} * W_j)} * 100, \quad (2)$$

where S_i = normalized allocation score for i^{th} riparian (0 and 100 percent); and W_j = weight assigned to j^{th} factor with $\sum_1^j W_j = 1$.

3 RESULTS AND DISCUSSION

3.1 Estimated groundwater resources

The groundwater aquifers within the JRB are depicted in Fig. 1 with corresponding surface area identified within the basin’s boundaries and reported safe yields presented in Table 2. In the Upper JRB, the steady flowing core of the Hasbani, Baniyas and Liddan rivers reflect groundwater-fed “base flows” with the bulk of the base flow for the Liddan River (241–249 MCM/year) originating from Lebanon and Syria [11], [20]. The karstic limestone geology of the area supports the notion of an intimate connection between groundwater and surface flows as well as the presence of fractured conduits that map across the international political borders of Israel–Lebanon or Israel–Syria. While the direction and flow rates of the groundwater are not monitored in Lebanon and Syria and are poorly monitored or reported in Israel, estimates of 250–350 MCM/year of transboundary groundwater crossing from Lebanon to Israel have been reported implying a significant contribution to the total transboundary water flows in the Upper JRB [11]. Despite the uncertainty around these estimates, it can still be argued that recharge areas for major springs in the Upper JRB are connected to transboundary groundwater resources, where the entire recharge zone of the Liddan Springs lies in Lebanon and Syria [22]. In the Lower JRB, groundwater resources play a more prominent role whereby the Yarmouk aquifer and other groundwater basins exist within the boundaries of the Lower JRB (Fig. 1) including Kinneret/Tiberias aquifer (62 MCM/year), the side wadis along the eastern escarpment of the Jordan Valley (~15 MCM/year), the Jordan Valley floor area (~21 MCM/year), and the Amman-Zarqa basin (87.5 MCM/year) [19], [18]–[35]. In addition, there is the Mountain Aquifer, a transboundary aquifer west of the Jordan River extending over Israeli and the Palestinian territories. The



Table 3: Evaluation of the Basin's water allocation based on international law factors.

Factor	Estimation Approach	Reference	Unit	Israel	Jordan	Lebanon	PA	Syria
F1 – Basin geographical area	Average riparian share of the total basin area reported by several references. Golan Heights area considered as part of Syrian territory.	[11]	km ²	2,032.3	6,764.0	740.0	1,879.5	6,640.3
		[20]	km ²	1,840.8	7,183.0	606.0	1,542.0	6,932.2
		[21]	km ²	1,906.0	7,352.0	688.0	1,564.0	6,775.0
		[9]	km ²	1,867.0	7,663.0	664.0	2,344.0	7,301.0
	Average	Average	km ²	1,912	7,241	675	1,832	6,912
		Score	%	10.3	39.0	3.6	9.9	37.2
F2 (a) – Water flow as only surface water	(a) Average annual riparians' contribution to surface water discharge.	[11]	MCM/year	501.3	217.3	147.1	115.1	445.6
		[22]	MCM/year			120.0		
		Average	MCM/year	501.3	217.3	133.6	115.1	445.6
		Score	%	35.5	15.4	9.5	8.1	31.5
F2 (b) – Water flow considering ground water resources	(b) Average annual riparians' contribution to groundwater resources. Golan Heights groundwater accounted for as contribution by Syria.	[11]	MCM/year	57.3	126.5	36.9	129.1	285.5
		This study (Table 2)	MCM/year	43.1	126.0	65.0	120.8	158.7
		Average	MCM/year	50.2	126.3	51.0	125.0	222.1
F2 (a & b) – Water flow for surface and ground water	Estimated annual riparians' contribution to surface and ground water by adding averages of F2(a) and F2(b).	Total Average	MCM/year	551.5	343.6	184.5	240.1	667.7
		Score	%	27.8	17.3	9.3	12.1	33.6
F3 – Precipitation	Average annual rainfall over the riparian areas of the JRB. Precipitation over Golan Heights considered as Syrian.	[11]	MCM/year	984.8	1,900.3	380.7	714.0	2,062.5
		[9]	MCM/year	343.5	1,701.2	337.3	846.2	3,708.9
		Average	MCM/year	664.2	1,800.7	359.0	780.1	2,885.7
		Score	%	16.3	31.4	6.3	11.8	34.1
F4 (a) – Existing surface water utilization	Reported riparian water abstraction from JRB surface water. Abstractions by Arabs within the Golan Heights considered as part of the Syrian water consumption.	[11]	MCM/year	607.3	243.2	5.9	5.3	181.9
		[11]	MCM/year	531-781	290.0	8 to 11	0.0	219-279
		[16]	MCM/year	781.2	235.0	5.0	0.0	178.8
		[22]	MCM/year	577.2	135.0	3.7	0.0	183.8
		[9]	MCM/year	791.2	340.0	5.0	20.0	183.8
		[20]	MCM/year	564-621	4.4			
		Average	MCM/year	656.9	248.6	6.1	5.1	204.3
		Score	%	58.6	22.2	0.5	0.5	18.2



Table 3: Continued.

Factor	Estimation Approach	Reference	Unit	Israel	Jordan	Lebanon	PA	Syria
F4 (b) – Existing groundwater utilization	Estimated riparian groundwater abstraction. Abstractions by Arabs within Golan Heights considered as Syrian water consumption.	[11] [20] [22] Average	MCM/year MCM/year MCM/year MCM/year	30.5	354.7	9.7	74.6	279.6
F4 (a & b) – Existing surface and groundwater utilization	Estimated riparian surface and groundwater abstraction by adding the average of F4(a) and F4(b).	Total Average Score	MCM/year %	716.0 38.5	546.0 29.3	12.5 0.7	96.9 5.2	489.2 26.3
F5 – Economic needs	As national agricultural contribution to GDP for 2010-2011.	Agricultural GDP Score	% %	2.3 ^a 7.4	2.9 ^b 9.4	4.0 ^c 12.9	5.5 ^d 17.7	16.3 ^e 52.6
F6 – Social needs	Represented as the national agricultural workforce for 2007, 2008, 2011, and 2012.	Agricultural workers Score	% %	1.6 ^a 4.0	2.0 ^b 5.0	7.2 ^c 18.1	11.9 ^d 30.0	17.0 ^e 42.8
F7 – Within Basin population	Country population living within basin area as estimated by 2007-2012. Golan Heights Arab residents considered within Syrian.	[11] [20] [11] Average Score	Number Number Number Number %	1,092,886 324,000 708,443 9.3	4,852,716 5,050,000 4,951,358 65.2	69,376 105,000 135,000 103,125 1.4	735,280 401,000 568,140 7.5	1,207,388 1,320,000 1,263,694 16.6
F8 – Costs of alternative water sources	Scores for economic burden based on reported desalination cost	Cost of desalinated water Score	USD/m ³ %	0.65 ^f 13.9	1.34 ^g 28.7	0.65 ^h 13.9	1.11 ^g 23.8	0.92 ⁱ 19.7
F9 – Availability of other water resources	Water Stress Index: national water demand based on a per capita water demand of 500 m ³ /year/riparians' annual national fresh water supply.	Available water resources ^j Year 2020 population Water demand Water stress index Score	MCM/year Millions MCM/year index %	2,040 9.10 ^k 4,385 2.23 11.6	1,020 8.09 ^l 3,785 3.97 20.7	1,370 4.88 ^l 2,355 1.78 9.3	244 5.14 ^l 2,870 10.53 20.0	19,950 25.74 ^l 15,235 0.65 3.4
F10 – Potential for appreciable harm	Water shortage considered to cause equal harm across countries. So equal equity scores assigned to all.	Score	%	20.0	20.0	20.0	20.0	20.0

^a [23]; ^b [24]; ^c [25]; ^d [26]; ^e [27]; ^f [28] [29]; Seawater desalination cost as low as 0.40 USD/m³ [29], with a higher limit of 0.65 USD/m³ [28]. ^g [30]; ^h Desalination cost for Lebanon assumed to be the same as that incurred by Israel due to similarity of coastal areas; ⁱ [31]; ^j [32]; ^k [33]; ^l [34].

aquifer in its North-eastern basin is estimated at ~130 to 145 MCM/year, while flows in the Eastern basin range between 125-172 MCM/year [15], [34]. Currently, the Mountain Aquifer is the subject of an independent transboundary water sharing agreement ratified by Israelis and Palestinians. Only small portions of the western Galilee, El-Azraq and Dead Sea basins' surface areas appear to lie within the JRB.

The resulting estimated groundwater resources within the JRB by riparian country (Table 2) show that the greatest amount of groundwater seems to be available in Syria, Jordan, and the PA followed by Lebanon at 65 MCM/year. These riparians contribute almost 87% of the JRB groundwater safe yield estimated at 513 MCM/year.

Another estimate of groundwater resources within the JRB [13] exhibited similar results except for difference in estimated quantities for Lebanon and Syria. SIDA [13] considered around 29% and 9% of groundwater safe yield from Lebanon to be inflow to Israel and Golan Heights, respectively, and consequently estimated Lebanon's groundwater at only ~37 MCM/year. On the other hand, SIDA [13] estimated Syria's groundwater at 255 MCM/year based on an interpretation of water abstraction rates cited in UN-ESCWA and BGR [20]. For Israel, Jordan, and the PA, the estimates are consistent mainly due to more readily available data about groundwater resources within these portions of the basin.

3.2 Transboundary water allocations

The scores of the quantified international water law allocation factors by riparian country reveal that 1) the highest percentage of the basin's catchment area are attributed to Jordan and Syria; 2) the highest percentage of surface water discharge into the basin is attributed to Israel followed by Syria and Jordan, while the highest percentage of surface and ground water discharge into the basin are attributed to Syria followed by Israel and Jordan; 3) Israel, followed by Jordan and Syria are the greatest users of the basin's surface and ground water resources; 4) the highest percentage of rainfall occurs in Syria and Jordan; 5) the highest within basin population and consequently the highest expected water demand among the basin's riparians are in Jordan followed by Syria; and 6) though Palestinians are entitled to a share in the basin's water, they are currently using 0.5% of its surface waters and ~5% of its overall surface and ground water resources.

According to Table 4 and under the baseline scenario of equal weights, Israel's share in the JRB surface water is evaluated at ~19%, Jordan's ~26%, Lebanon's 10%, the Palestinian Authority's ~18%, and Syria's ~28%. However, when considering both surface and ground water resources under the baseline scenario of equal weights, Israel's share becomes ~15% and Syria's ~30% while Jordan's, Lebanon's, and the Palestinian Authority's remain more or less the same (Table 4). The observed changes in shares is due to changes in contribution of each riparian to water discharge (F2) and to water utilization rate (F4). Moreover, considering both surface and ground water reduced the levels of perceived inequity albeit by relatively small ranges. For example, Israel's exceedance was reduced by 13.3% because groundwater within the Israeli portion of the JRB contributes small amounts compared to available surface water and Israel is abstracting the majority of the surface water. Though under scenario 1 of considering both ground and surface water Jordan appears to be close to exceeding its share by ~5%, this requires care in analysis as Jordan is known to be over abstracting from its groundwater resources and the sources of over abstracted quantities are not verified whether they belong to the JRB or not.

Under the scenario 2 (experts assigned weights), Israel's share in the JRB surface water is evaluated at ~25%, Jordan's ~27%, Lebanon's 8%, the Palestinian Authority's ~15%, and



Syria's ~26%. However, when considering both surface and ground water resources of the JRB, the shares become ~19% for Israel, ~28%, Jordan's, ~7% Lebanon's, ~16% the Palestinian Authority's, and ~30% Syria's (Table 4). Under scenario 2, considering both surface and ground water resulted in enhancing Israel's level of exceedance by ~4% since the experts assigned weights tend to emphasize more the factors related to water flow (F2), precipitation (F3), and existing use (F4). For other riparians, similar trend as under the equal weights scenario was observed.

Overall, the allocations under the various scenarios and considerations (Table 4) indicate that irrespective of the assigned weights, if the international water law criteria were enforceable, then Israel would be considered to be exceeding its potential share given that the existing allocation pattern of Israel (~59% of the JRB surface waters and ~38% of surface and ground water supplies) cannot be attained. This is emphasized by the similar trends observed under scenario 1 (equal weights) and scenario 2 (average of experts assigned weights), where Israel continues to be over utilizing its potential share and the remaining riparians underutilizing theirs. Thus, the influence of groundwater mainly resulted in reducing Israel percentage share from 19–25% range when considering surface water only to 15–19% of both surface and ground water resources. The remaining riparians shares were either enhanced or did not witness a considerable change (Lebanon). On the other hand, Lebanon's and the PA's should be using more of the basin's water resources given that they are greatly underutilizing their potential shares. The unobservable change for Lebanon's share when accounting for groundwater resources emphasizes that Lebanon is not exploiting its water supplies within its territories of the JRB.

Table 4: Water allocation when accounting for sources under equal factors weights.

Category	Condition	Israel	Jordan	Lebanon	PA	Syria
		Percent (%)				
Surface water*	Existing use	58.6	22.2	0.5	0.5	18.2
	Equal weights (scenario 1)	18.7	25.7	9.6	18.4	27.6
	Average of experts assigned weights (scenario 2)	24.8	26.6	7.6	14.7	26.4
	30% of weight assigned to one factor (scenarios 3 to 12)	15.4–27.6	21.1–34.5	7.6–11.9	14.4–26.5	22.2–33.2
	Over or underutilization based on equal weights	+148.6	-31.5	-95.4	-98.1	-47.7
	Over or underutilization based on experts' weights	+87.4	-33.8	-94.2	-97.6	-45.2
Surface and ground water**	Existing use	38.5	29.3	0.7	5.2	26.3
	Equal weights (scenario 1)	15.3	26.2	9.5	19.3	29.7
	Average of experts assigned weights (scenario 2)	18.8	27.8	7.4	16.2	29.7
	30% of weight assigned to one factor (scenarios 3 to 12)	12.8–20.5	21.5–34.9	7.7–11.8	16.2–27.2	23.8–34.8
	Over or underutilization based on equal weights	+135.3	+4.7	-93.3	-74.8	-17.0
	Over or underutilization based on experts' weights	+91.9	-1.2	-91.5	-70.0	-17.2

* Surface water estimated at ~1,413 MCM/year; ** Surface and groundwater estimated at ~1,927 MCM/year.



Finally, it is imperative to emphasize that in the absence of a database that have the consensus of all riparian countries, estimations reported in this study are only indicative and may provide a starting point for policy discussions until a comprehensive database is agreed upon by riparians. This also raises the need for a dynamic water allocation based on percentages rather than volumes which can accommodate variations in available natural water supplies due to the potential impacts of climate change for instance.

4 CONCLUSION

The reasonable shares of riparian countries from the transboundary waters of the JRB were evaluated based on the international water law criteria with considerations to both surface and ground water resources. The results revealed that current allocation patterns in the JRB are skewed. According to the international law factors and while accounting for the combined surface and groundwater resources, Israel's percentage share of the JRB water resources may range between 12.8–20.5%, Jordan's between 21.5–34.9%, Lebanon's 7.7–11.8%, the Palestinian Authority's 16.2–27.2%, and Syria's 23.8–34.8%. Accounting for groundwater resources reduced Israel's share by 2.6–7.1%. Additional characterizations for groundwater resources within the basin are imperative to define relevant safe yields and potential lateral flows that may influence the distribution of reasonable water shares within the JRB.

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