Use of MedWater model outputs as indicators

Kosatica, E.[1)], Noorudin, J.[1)], Koellner, T. [1)], Bresinsky, L.[2)], Kordilla, J.[2)], Sauter, M.[2)], Hepach, P.[3)], and Engelhardt, I.[3)]

[1)] *Professorship for Ecological Services, Faculty of Biology, Chemistry and Geosciences, University of Bayreuth*
[2)] *Applied Geology Department, University of Göttingen*
[3)] *Hydrogeology Department, Technical University of Berlin*

The following indicators have been selected by MedWater partners based on their applicability and usefulness to the project while also taking into account each partner's ability to provide outputs that can be used as specific indicators. The indicators are a result of multiple discussions within the project as well as review of indicators in other projects. They are primarily determined by the outputs of the different models and calculations by the project partners.

Indicator 1 – *Change in water table and spring discharge relative to the red lines*

This indicator quantifies the change of aquifer water level and spring discharge relative to the red lines as the difference to the red line. The red lines are defined by the Israeli Water Authority and represent specific levels of risks with regards to the integrity of the aquifer and ecosystems. A drop of the groundwater levels below the red lines may activate saltwater intrusion from the Mediterranean Sea. Further, the red line indicates a depletion of fossil groundwater. A decrease of spring discharge below the red line poses a risk to ecosystems in the vicinity of springs. The red line for the spring discharge of the Taninim/Al Timsah spring equals 0.5 m^3/s. The purple line, i.e., reactivation of the Yarkon/Ras Al Ain spring, is not considered here, as all scenarios do not lead to a reactivation of this spring.

The red lines for groundwater levels are defined as follows:

- In the northern part: +9 m.a.s.l.
- In the central part: +12 m.a.s.l.
- In the southern part: +13 m.a.s.l.

The water level and spring discharge were calculated using the HydroGeoSphere and MODFLOW models. The calculation was done for three different scenarios. The Baseline scenario which is essentially a business-as-usual situation simply continues the current trends. The Regional Resource Intensive scenario maximizes the use of the aquifer, extracting large volumes of water in order to meet the demand. The Regional Nature Conservation scenario focuses on limiting groundwater extraction and rather assumes additional water demand will be met from other sources.

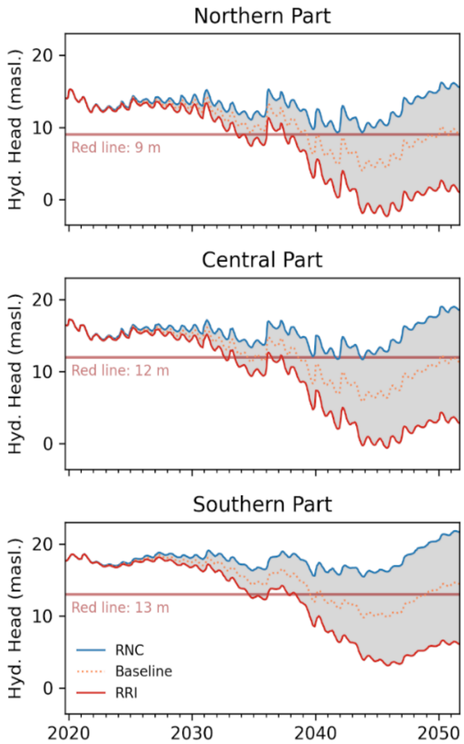


Figure 1: Groundwater levels relative to the red line based on HydroGeoSphere

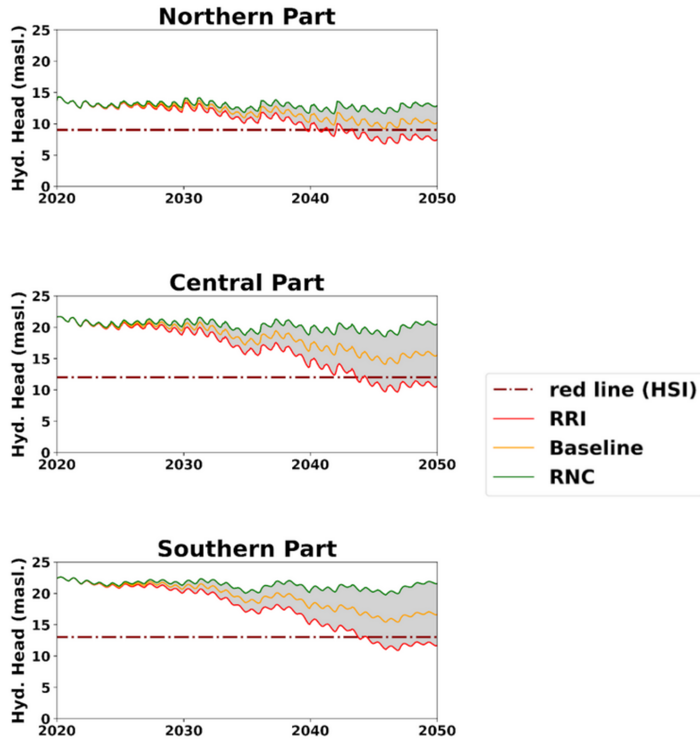


Figure 2: Groundwater levels relative to the red line based on MODFLOW

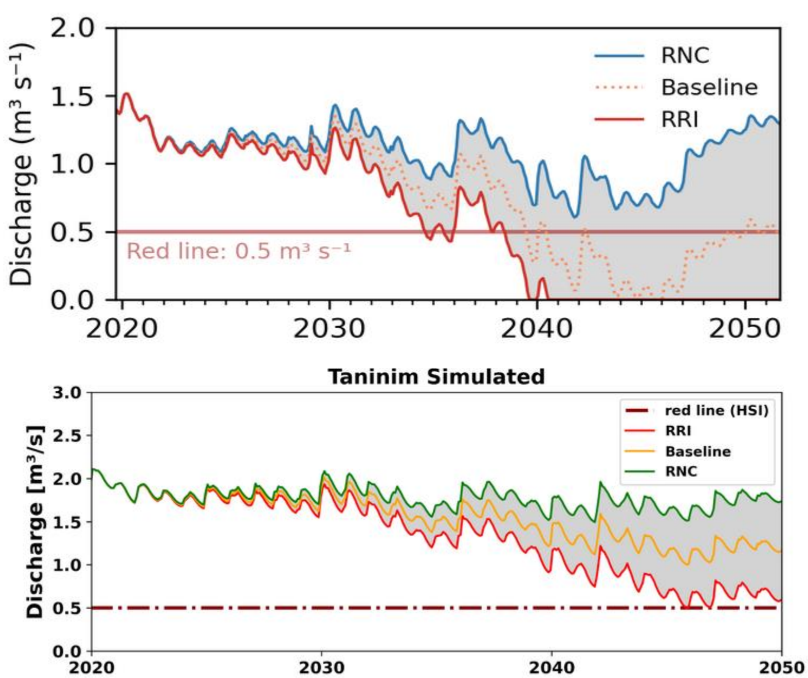


Figure 3: Spring discharge at the Taninim/Al Timsah spring relative to the red line based on HydroGeoSphere (Top) and MODFLOW (Bottom)

Indicator 2 – a) Total water volume in Western Mountain Aquifer, b) Virtual water imports and exports

The total water volume can be used as an indicator of water security and the resilience of the water supply system in Israel. It is a theoretical volume that could be extracted, however, it would likely cause irreparable damage to the aquifer through saltwater intrusion. In Figure 4, we see how the water volume would change based on the different scenarios.

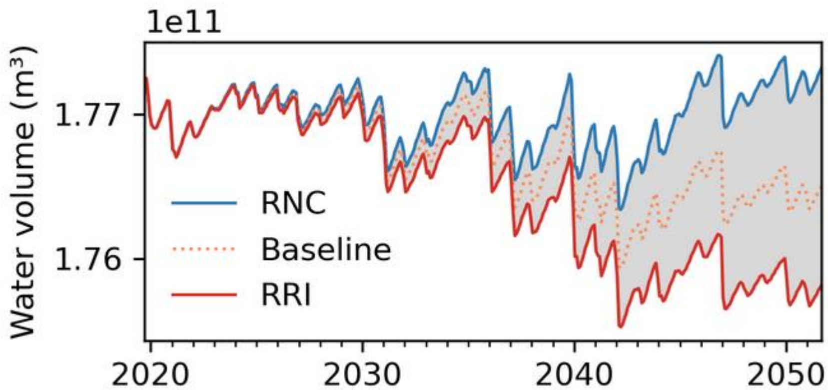


Figure 4: Total water volume in the Western Mountain Aquifer is between 176 000 and 177 000 million m³

The virtual blue water embedded in imports and exports enables a calculation of the water budget of Israel, identifying the level of reliance on external water sources compared to locally available water.

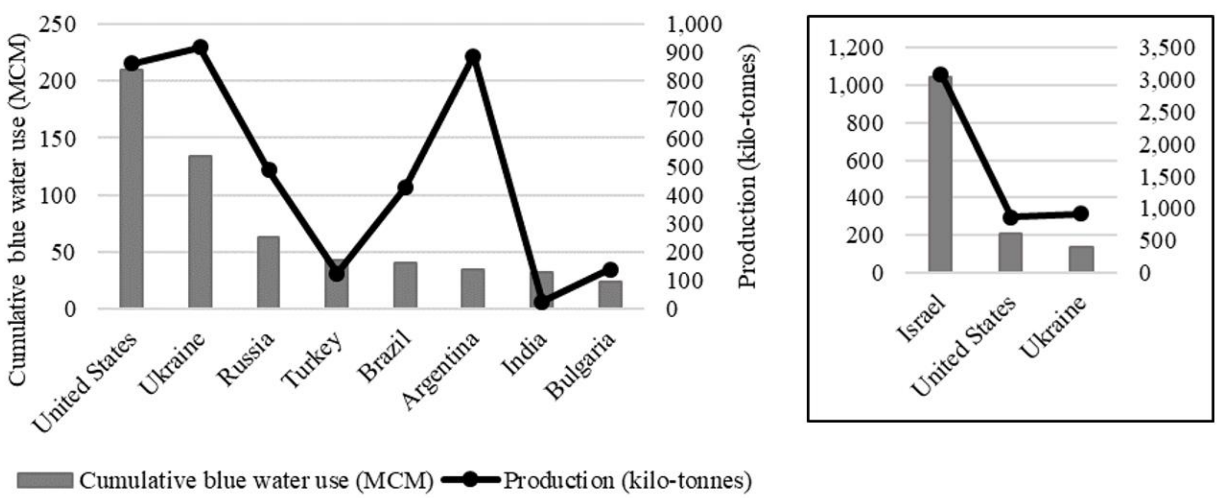


Figure 5: Blue water use (derived from Pfister & Bayer (2014) dataset) compared to production quantities of countries with highest cumulative blue water use. The left figure compares 8 countries excluding Israel (which would otherwise dwarf other countries), while the right compares the three highest cumulative blue water users. Line markers lower on a production bar relative to other production bars with line markers indicate less blue water used per unit of production relative to other countries.

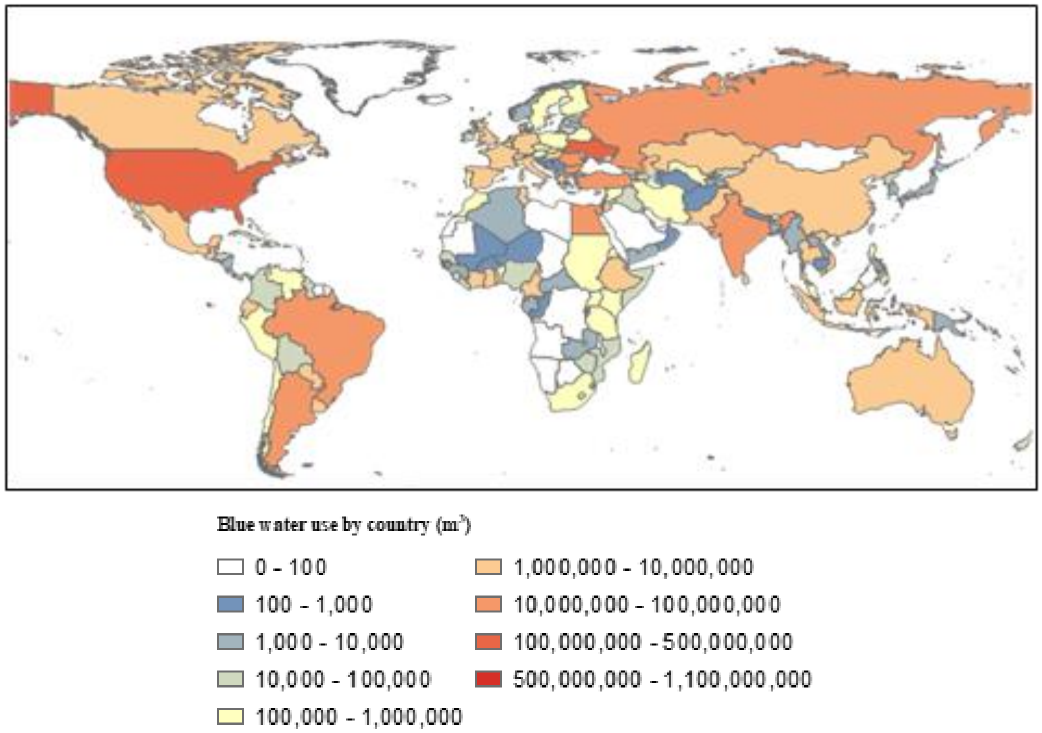


Figure 6: Blue water use associated with Israel's crop consumption of imported and locally produced crops

Israel's virtual water consumption related to crops is around 1,806 million m^3 of blue water and 6,498 million m^3 of virtual green water. From the total blue water consumption, 1,044 million m^3 originated from Israel's domestic production. Israel exported a relatively smaller amount of 132 million m^3 of virtual blue water. From these data, we conclude that Israel predominantly relies on rainfed crops, i.e., green water. In terms of blue water, the largest share of consumption is located in Israel itself.

Indicator 3 – Runoff Coefficient

The runoff coefficient indicates the percentage of water that passes through the system without necessarily being used by humans. It also potentially indicates "nature's share" of the water coming into the system via precipitation. Water that infiltrates is excluded from the calculation. Stream discharge from a SWAT model in m³/s is used to calculate the volume of water which is then divided by the precipitation to calculate the coefficient.

Station ID	Station Name	Scenario				
		Current	Climate	Baseline	RNC	RRI
		2000-2015	2021-2050	2021-2050	2021-2050	2021-2050
14120	HADERA - Gan Shemu'él	21.0%	14.4%	13.7%	14.3%	14.3%
15120	ALEXANDER – Elyashiv	19.1%	8.5%	8.5%	8.4%	8.5%
17135	YARQON – Herzliyya Road	18.6%	13.1%	13.0%	13.0%	13.0%
17168	AYYALON – Shekhunat 'Ezra	32.3%	17.2%	17.2%	17.1%	17.2%
18180	GAMLI'ÉL – 42 Road	61.7%	54.0%	54.2%	53.6%	53.7%
19185	LAKHISH – Ad Halom Park	55.4%	48.6%	48.6%	48.0%	48.3%
21130	SHIQMA - Beror Hayil	36.6%	23.5%	23.2%	23.1%	23.4%
23160	GERAR - Re'im	35.7%	23.9%	24.3%	23.4%	24.8%

Table 1: Runoff coefficients for selected gauging stations in the Western Mountain Aquifer basin based on the different scenarios

The results indicate a reduction of the runoff coefficient which is primarily determined by climate change. The variation in the coefficient for the three scenarios is quite low.

Indicator 4 – Peak Water Discharge

The Peak Water Discharge (PWD) is provided by the SWAT model as peak streamflow on a daily time scale. The PWD expresses the maximum discharge that the hydrographic network of the catchment can produce, given in m^3/s.

Station ID	Station Name	Scenario				
		Current	**Climate**	**Baseline**	**RNC**	**RRI**
		2000-2015	**2021-2050**	**2021-2050**	**2021-2050**	**2021-2050**
14120	HADERA - Gan Shemu'él	25 m3/s: six times in 15 years	5 m3/s: two times in 30 years	6 m3/s: three times in 30 years	10 m3/s: once in 30 years	10 m3/s: once in 30 years
15120	ALEXANDER – Elyashiv	25 m3/s: eight times in 15 years	10 m3/s: once in 30 years	10 m3/s: once in 30 years	10 m3/s: once in 30 years	10 m3/s: once in 30 years
17135	YARQON – Herzliyya Road	30 m3/s: nine times in 15 years	10 m3/s: four times in 30 years	10 m3/s: five times in 30 years	20 m3/s: once in 30 years	20 m3/s: once in 30 years
17168	AYYALON – Shekhunat 'Ezra	20 m3/s: five times in 15 years	10 m3/s: once in 30 years	10 m3/s: once in 30 years	10 m3/s: once in 30 years	10 m3/s: once in 30 years
18180	GAMLI'ÉL – 42 Road	25 m3/s: five times in 15 years	No peak discharge	5 m3/s: once in 30 years	5 m3/s: two times in 30 years	5 m3/s: once in 30 years
19185	LAKHISH – Ad Halom Park	100 m3/s: once in 15 years	10 m3/s: two times in 30 years	15 m3/s: two times in 30 years	15 m3/s: once in 30 years	20 m3/s: once in 30 years
21130	SHIQMA - Beror Hayil	50 m3/s: once in 15 years	10 m3/s: two times in 30 years	10 m3/s: two times in 30 years	10 m3/s: two times in 30 years	10 m3/s: two times in 30 years

Table 2: Peak Water Discharge for selected gauging stations in the Western Mountain Aquifer basin based on the different scenarios

In Table 2, we see the different peak water discharges and their return interval in 15 and 30 years. The results indicate a reduction in PWD primarily driven by climate change and an overall reduction in precipitation. Based on the results, it is likely that the modeled climate data does not capture extreme events properly.

Indicator 5 – Ecosystem services indices

I5 consists of multiple indices for different ecosystem services. Here we focus on the Index for Regulation of Surface water quantity, location, and timing (IRSWQLT), Index for Regulation of Groundwater quantity, location, and timing (IRGWQLT), Index for Regulation of Surface Freshwater Quality (IRWQ), Index for Protection of Soils and Sediments (IPSS), and Index for Food and Feed (IFF).

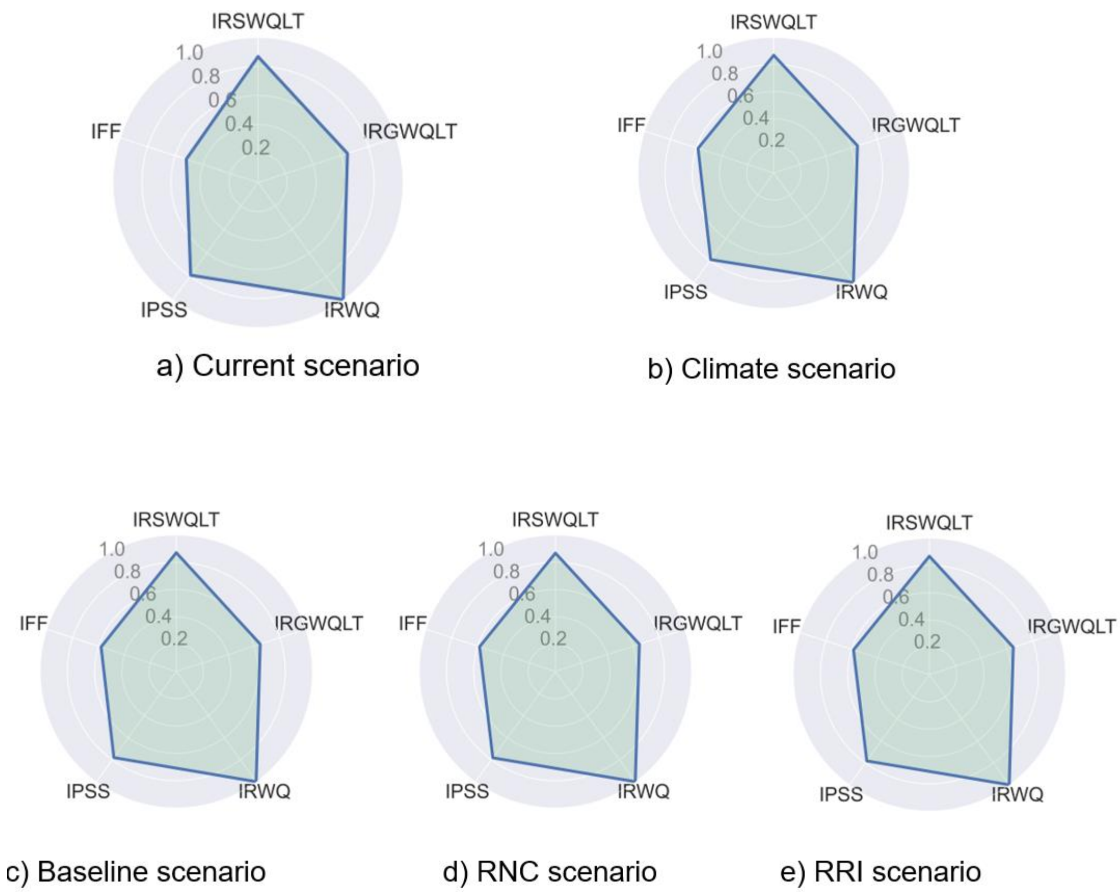


Figure 7: Changes in Ecosystem Services Indices for different scenarios in the recharge zone of the Western Mountain Aquifer basin

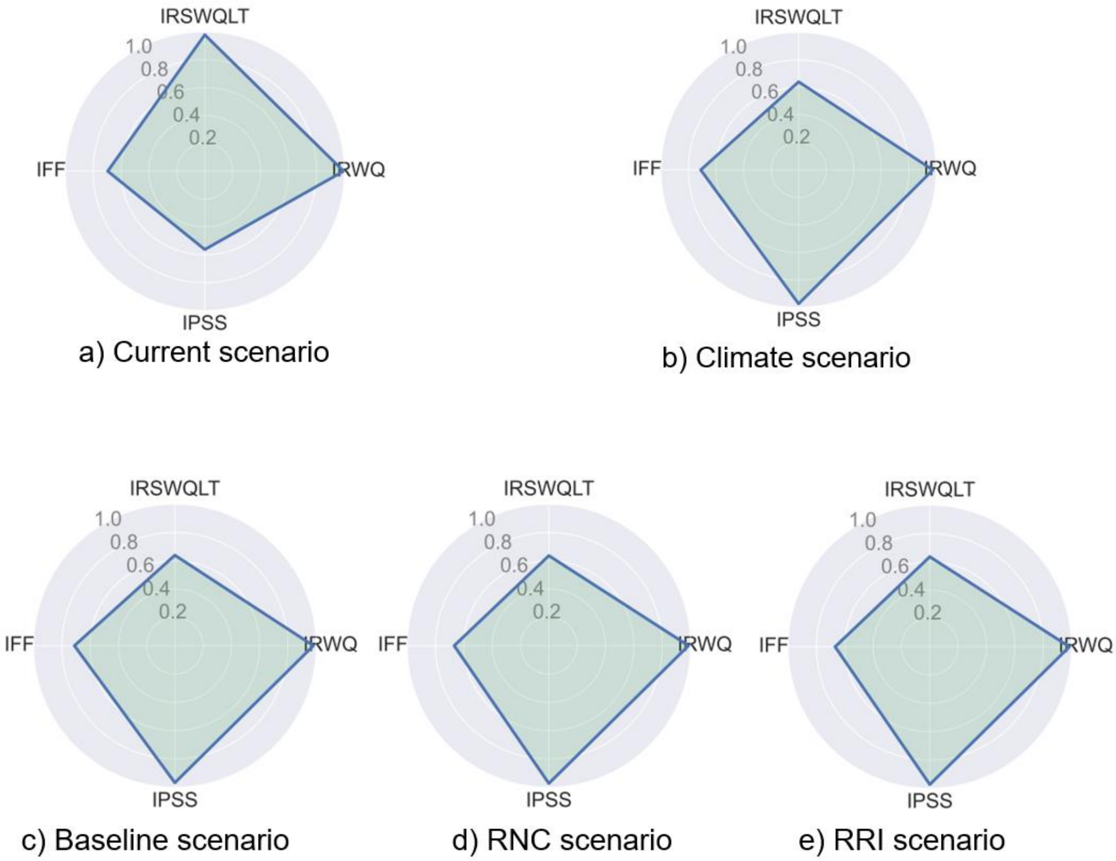
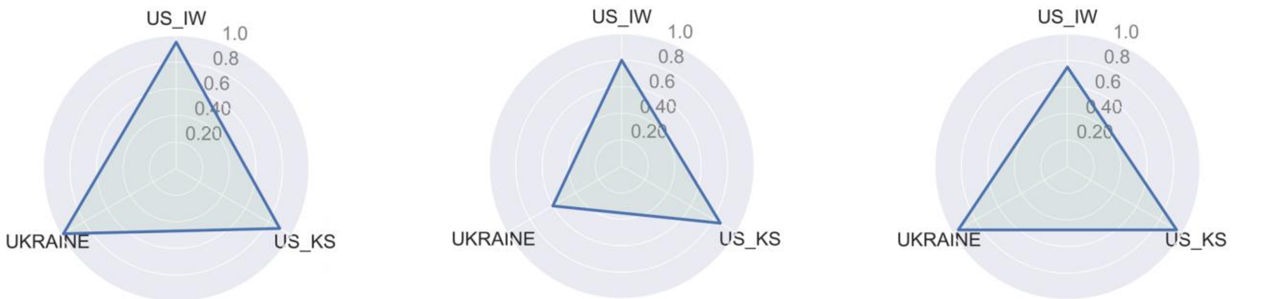


Figure 8: Changes in Ecosystem Services Indices for different scenarios in the non-recharge zone of the Western Mountain Aquifer basin

The non-recharge zone of the basin does not provide water for the WMA. Therefore, the Index for Regulation of Groundwater quantity, location, and timing is removed. The current indices for different ecosystem services are compared with the indices of ecosystem services under future climate change conditions for the recharge and non-recharge zone. The IRSWQLT is 0.83 for the recharge zone and 0.95 for the non-recharge zone. This means that river discharge meets environmental flow requirements 83% and 95% of the time. The IRGWQLT of 0.84 means that groundwater recharge provides 84% of the sum of groundwater abstractions and spring discharge. For both regions, the nitrate concentration is very low, which results in very high water quality regulation indices. Both regions have high relative areas of barren (19%) and urban land (17%), and only 35% of the agricultural area includes field crops, vegetables, and significant areas of orchards. Therefore, the index for food and feed is very low in both regions. The index for protection of soils and sediments is also moderate to high, which means soils are well protected. Under future climate change conditions, the indices for regulation of surface water and groundwater quantity, location, and timing decrease alarmingly because of the reduced precipitation and increase in temperature. While the indices for regulation of water quality and protection of soils and sediments remain high, the index for food and feed drops significantly. This indicates that more food may need to be imported in the future.



Index for Regulation of Surface water quantity, location, and timing

Index for Food and Feed

Index for Protection of Soils and Sediments

Figure 9: Ecosystem Services Indices for different regions where Israel's imports are coming from: Sula river in Ukraine, North and South Fork Solomon river in Kansas, and Little Sioux river in Iowa.

When comparing three watersheds representative of crop exports to Israel in terms of surface water regulation, the index is relatively high for all three cases (Ukraine 0.98; Iowa 0.95; Kansas 0.90). The protection of soils and sediments index shows a slight differentiation between the watersheds with Iowa having a somewhat lower index (Ukraine 0.95; Iowa 0.85; Kansas 0.96). This is likely due to higher precipitation and having only corn-soybean rotation dominating the watershed. When we look at the food and feed provisioning index, Iowa and Kansas stand out significantly over the Ukrainian watershed (Ukraine 0.60; Iowa 0.80; Kansas 0.86). This is primarily driven by the lower yields in Ukraine, which means that the USA watersheds are more efficient food producers. Based on the results for these three services it appears that crop production in the USA is more efficient when all ES are taken into account than in Ukraine. An analysis of ES flows can enable policy makers to identify countries and watersheds that have high ES indices and from which they could import crops while reducing environmental impacts. Similar to virtual water, the concept of virtual ES provides an additional lens through which to investigate the reliance of importing countries on ecosystems abroad and identify non-linear trade-offs.

Indicator 6 – Stress Impact Value

The Water Stress Index (WSI) is used to quantify water scarcity, or "… the fraction of water consumed of which other (downstream) users are potentially deprived" (Pfister & Bayer, 2014). The WSI, ranging between 0 and 1, acts as a CF [Characterization Factor] for application within the midpoint category "water deprivation" in LCIA. Applying the WSI to the virtual water volumes, we can derive the Stress Impact Value (SIV).

Country	Ranking pre-WSI	Direction	Ranking post-WSI	Position changes	% decrease
Israel	1	→	1	0	9
United States	2	→	2	0	60
Ukraine	3	→	3	0	64
Turkey	5	↗	4	+1	46
India	8	↗	5	+3	27
Gaza Strip	11	↗	6	+5	0
Bulgaria	9	↗	7	+2	62
Russia	4	↘	8	-4	89
Spain	9	→	9	0	27
Egypt	12	↗	10	+2	64
Argentina	6	↘	11	-5	87
Romania	10	↘	12	-2	77
Brazil	7	↘	13	-6	93

Figure 10: Comparison of 13 country rankings of blue water use (derived from Pfister & Bayer (2014) dataset) before the application of Water Stress Index (WSI) data to produce the Stress Impact Value (SIV), and after, including direction of change in rankings, number of position changes, and percent decrease in water volumes associated. Countries featured comprised the highest 10 SIVs and blue water values. A blue arrow indicates a ranking that has remained the same, while green and red indicate a fall and rise in rankings, respectively.

By using the WSI as a characterization factor in LCIA terms where we weigh the blue water based on WSI, we derive a Stress Impact Value for each country which enables us to identify blue water use hotspots in Israel's crop consumption. The results show that the top three countries in terms of blue water volumes, namely Israel, United States, and Ukraine remained the top three in terms of the Stress Impact Value as well. This is primarily due to the large amount of Israel's consumption originating from these countries. What is worth noting though is that Israel itself has become much more prominent, i.e., the gap between Israel and other countries becomes much larger since the Water Stress Index in Israel is much higher than in the United States or Ukraine. The countries that also became more prominent due to water stress are

Turkey, India, Bulgaria, and Egypt. The countries that became less relevant, meaning that the blue water volume when weighted by the water stress index caused them to drop in the rankings are Russia, Argentina, Romania, and Brazil, among others. What these results show is that virtual blue water imports from Russia, Argentina, Romania, and Brazil have a much smaller impact on water users in those countries, rather than imports from Turkey, India, Bulgaria, and Egypt.

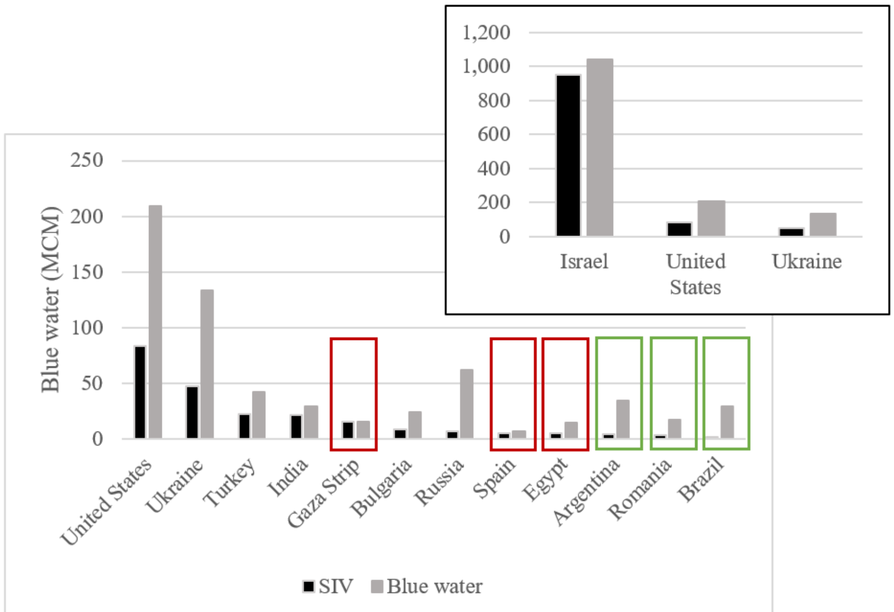


Figure 11: Blue water volumes associated with Israel´s consumption per country of production. Volumes of blue water use under the Pfister & Bayer (2014) schema of 13 countries contrasted with volumes of Stress Impact Values (SIV), accumulated to country level. The inset compares the three highest cumulative SIVs, while the main figure compares those of the 12 highest, excluding Israel. Countries are a combination of those with the highest 10 SIVs and blue water values. Bars surrounded in green indicate countries that dropped out of the top 10, while bars surrounded in red indicate countries that entered the top 10, after the application of Water Stress Index (WSI) to produce SIV.

Indicator 7 – Fractions of potential species extinctions per cubic meter of water

The quantity of water appropriated by humans results in a lack of water available for nature/wetlands leading to a loss of habitat and therefore species. This indicator is calculated using global water footprint datasets combined with the LC-Impact Characterization Factors expressed as global fractions of potential species extinctions per cubic meter of water consumed. It is important to keep in mind that the biodiversity impacts primarily concern aquatic and wetland species that are dependent on blue water, and therefore the terrestrial biodiversity impacts due to land use change are not included in this method.

Country	Cumulative BIV (PDF per year)	Crop	Cumulative BIV (PDF per year)
United States	1.91290×10^{-4}	Wheat	1.0820×10^{-4}
Israel	0.11628×10^{-4}	Soybeans	0.4026×10^{-4}
Australia	0.02309×10^{-4}	Maize	0.3028×10^{-4}
Jordan	0.01271×10^{-4}	Olives	0.0272×10^{-4}
Canada	0.01047×10^{-4}	Sunflowers	0.0211×10^{-4}
Turkey	0.00753×10^{-4}	Apples	0.0160×10^{-4}
Thailand	0.00457×10^{-4}	Peaches & nectarines	0.0112×10^{-4}

Table 3: Ranking in order of the magnitude of cumulative biodiversity impact values (BIV), expressed in potential disappeared fractions (PDF) per year, by seven highest countries across all crops, and seven highest crops across all countries

Indicator 8 – Regional crop production and crop imports and exports

Due to globalization, trade has become the dominant strategy for maintaining food security for many countries around the world. The data below illustrate Israel's dependence on imports, particularly of staple crops such as wheat, maize, and soybean.

Crop category	Produced	Imported	Exported
Vegetables	26 million	1 million	5 million
Fruits	31 million	1 million	6 million
Potatoes	11 million	600 thousand	4.6 million
Wheat	3 million	30 million	------
Maize	2 million	23 million	------
Barley	200 thousand	6 million	------
Soybean	------	9 million	------

Table 4: Israel's local production, imports, and exports of crops cumulated for 20 years (2000-2019)

If we assume similar consumption patterns (quantities and types of crops) and that the local production is already maximized, particularly since Israel has a rapidly growing population, then, for a roughly 55% population increase in the period 2050-2070, Israel would need to import:

- 46 million tons of wheat,
- 36 million tons of maize,
- 9 million tons of barley,
- 14 million tons of soybean.