Virtual water fluxes between Israel and the world – relevance for water resources and ecosystem services

Key issues identified by the MedWater project

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This report outlines the main research findings of the University of Bayreuth in the MedWater project. The primary focus is on virtual water flows and ecosystem services in Israel as well as regions exporting crops to Israel.

1) How dependent is Israel on imports?

Due to globalization trade has become the dominant strategy for maintaining food security for many countries around the world. In the last 20 years (2000-2019) Israel has produced various vegetables in large enough quantities (cumulatively more than 26 million tons based on FAOSTAT data) in order to satisfy the local demand. At the same time 5 million tons of vegetables were exported and more than 1 million were imported. Israel grew large quantities of different fruits with over 31 million tons, while exporting almost 6 million tons, and importing over 1 million tons. It also produced potatoes in large quantities, almost 11 million tons, while importing less than 600 thousand, and exporting 4.6 million tons in these 20 years. But potatoes are the only staple crop that Israel produces enough of to satisfy local demand. The climate and land limitations mean that local production is quite limited in terms of producing all other staple crops. Israel has imported around 30 million tons of wheat in the same time period, while it has produced less than 3 million tons locally. It also imported more than 23 million tons of maize, while producing less than 2 million. The other two significant crops, particularly for use as fodder, are barley and soybeans. Israel imported over 6 million tons of barley while producing less than 200 thousand, and it also imported over 9 million tons of soybeans while producing none. It is clear from these numbers that in order to meet its population's nutritional needs Israel is extremely dependent on imports which can pose a significant food security risk.

2) What is the water footprint of Israel's imports and exports?

The virtual water use of imports and domestic crop production for Israel's consumption, and separately, Israel's crop production for export, were analyzed. In the first step, global data on the rate of water use (cubic meters of green and blue water per ton of primary crop equivalent) was applied to production data (in tons), to derive blue and green water use volumes by crop. Due to data availability, the primary crop production dataset is from 2005 and consists of bilateral trade and production data relating to 142 FAO crops, plus 239 processed products. A total of 1,806 million cubic meters (MCM) of virtual blue water and 6,498 MCM of virtual green water was used in the production of 100 crops for Israel's consumption in 2005. From the total blue water consumption 1,044 MCM originated from Israel's domestic production. Israel exported 132 MCM of virtual blue water. This represented 11.3% of the total blue water used in Israel's agricultural production. On the import side for domestic consumption wheat had the highest virtual water volume, followed by maize. On the export side potatoes, dates, grapes, and olives accounted for over 50% of the exported virtual water.

3) Do different water footprint databases make a difference?

It is important to point out that there are significant differences in virtual water volumes depending on the database or model used. For Israel we compared two global water footprint databases. The primary database used to calculate virtual water flows was from Pfister and Bayer (2014), since it provided water volumes on a watershed scale rather than just country averages. The second global database that was used for comparison was the Water Footprint Network (WFN) providing water volumes on a country level. The WFN database consistently produces lower country volumes, as well as a lower cumulative volume of blue water use of 1,083 MCM compared to the value of 1,806 MCM for cumulative Pfister and Bayer (2014). The volume of green water calculated based on the WFN amounted to 9,161 MCM compared to 6,498 MCM for cumulative Pfister and Bayer (2014) green water. The WFN data resulted in a completely different order of crops regarding cumulative volumes of associated blue water use compared to the Pfister and Bayer (2014) data. The cumulative virtual blue water volume for wheat consumed in Israel based on the PB data was 405 MCM, maize was second with 125 MCM, and apples third with 114 MCM. The cumulative virtual blue water volume for wheat based on the WFN data was only 63 MCM, maize 79 MCM, and apples only 50 MCM, rice was the second highest with 69 MCM compared to 45 MCM calculated with Pfister and Bayer (2014) data.

4) How efficient is irrigation in Israel compared to the USA?

When looking at irrigation efficiency, defined as blue water volume per ton of crop, we can see the differences in databases/models depending on the watershed or country average. Here we compare the results for Israel's imported wheat and maize from the USA and the production of those same crops locally in Israel. The production weighted country average for wheat in Israel is 631 m^3/ton and for maize it is 304 m^3/ton according to the PB dataset. For comparison we chose a watershed in Kansas that produces high quantities of wheat and maize where the blue water volume for wheat is 280 m^3/ton and for maize it is 159 m^3/ton. Such high quantities of blue water required for wheat and maize production in Israel clearly show the need to import these crops rather than produce them locally in a water scarce country.

5) Going beyond water volumes, how do the impacts change based on water stress?

The blue water volumes alone do not tell the whole story. Therefore, we also applied a Water Stress Index defined as "… the fraction of water consumed of which other (downstream) users are potentially deprived" (Pfister and Bayer 2014). 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 weighed 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.

6) How does the water abstraction affect aquatic biodiversity?

For the Biodiversity Impact Value (BIV) the characterization factors, expressed as global fractions of potential species extinctions per cubic meter of water consumed (Verones et al., 2016), were used to weigh the blue water imports. 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. The highest cumulative impacts across all crops were from the United States, approximately 16 times larger than that of the next highest value, Israel. All other countries ranked orders of magnitude lower than the United States. In terms of crops, wheat, soybeans, and maize were the most significant, with all other crops being an order of magnitude lower. The major caveat with respect to BIV is that the characterization factors are biased towards weighing the United States higher due to a high reported wetland density, whereas some other countries might have large wetland areas, but they are not reported as Ramsar designated wetlands.

7) How high are the energy and greenhouse gas emissions related to virtual water?

We also investigated the energy and greenhouse gas (GHG) emissions associated with Israel's blue water consumption. Depending on the water source, irrigation water supply can be particularly energy-intensive. The analysis also includes emissions associated with the transport of crops where overseas imports to Israel become particularly energy and GHG-intensive. The total energy consumption for crops consumed in Israel amounted to 2,359 GWh. It was attributable to domestic production by 24% (563 GWh) and to the import by 76% (1,796 GWh). The import component was so high mainly due to the energy consumption related to transport (72%), compared to 28% "energy for water". The artificial water supply with desalinated seawater (49%) and domestic wastewater (33%) was responsible for most of the domestic "energy for water". The total GHG emissions of 1,180 kt CO2e split into 37% (431 kt CO_2e) domestic and 63% (749 kt CO_2e) import. The main difference compared to energy consumption was the lower relative importance of import transport. Approximately 49% of total energy consumption and 42% of related GHG emissions of Israeli domestic and imported agricultural blue water were embedded into cereals, followed by oil crops (26% energy and 27% GHG) and fruits (11% energy and 16% GHG). Wheat produced in Israel had a domestic weighted average of 524 kWh/t (energy) and 401 kg CO_2e/t (emissions). Imported wheat from Ukraine, Romania, and Turkey was only around 60-285 kWh/t and 23-230 kg CO_2e/t. The results presented here clearly indicate the potential for optimization in order to reduce the energy and GHG emissions of Israel's crop consumption. Local production is associated with relatively high emissions, as is transport of crops over the Atlantic Ocean, while emissions from Ukraine, Romania, and Turkey appear to be less energy and emissions-intensive.

8) What is the current state of ecosystem services in Israel?

Ecosystem services are the positive contributions to humans provided by the natural environment and from healthy ecosystems. We investigated the current state of services provided by different ecosystems: regulation of surface water, regulation of groundwater, regulation of water quality, protection of soils, and food and feed provisioning. We used a modeling approach with the Soil and Water Assessment Tool (SWAT) and an index-based method with a scale of 0 to 1 (modified from Logsdon and Chaubey, 2013), where close to zero index value means minimal service is provided by the current ecosystem and 1 indicates the ecosystem is healthy enough to provide maximum services. The surface water regulation index for 14 different stations on six different rivers in Israel is 0.92 in the recharge zone and 0.98 in the non-recharge zone. These indices indicate that those rivers meet environmental flow requirements for most of the year. The index value is lower in the recharge zone because of heavy infiltration which increases the groundwater index to 0.83 indicating relatively high recharge compared to the sum of the well's abstractions and spring discharge. The water quality index is 0.99, which indicates that in most cases, the nitrate concentration in the water is lower than its permissible limit (70 mg/L). The index for soil protection is 0.73 and 0.56 in the recharge zone and non-recharge zone, respectively when the maximum allowable limit is set at 5 t/ha. The food supply index of 0.56 indicates that the current agroecosystem provides some food and feed supply, but there is still room for improvement. The results presented here indicate that the services provided by the current state of the ecosystem are suitable to high. However, the high population increases the pressure on the different ecosystems, for example, groundwater and food supply are insufficient for the current water and food demand. Therefore, the unmet demand for water and food in Israel is met by producing non-conventional water from desalination and wastewater treatment plants, and via imports of food and feed.

9) How will the provisioning of ecosystem services in Israel change depending on specific scenarios?

Future climate change presents a big threat to ecosystems and ecosystem services. In the MedWater project, along with future climate change scenarios, a road map to future land use change scenarios is considered based on population growth and food demand in Israel. Based on this we investigated the ecosystem services for one climate change scenario and three land use change scenarios (business as usual, regional nature conservation, and regional resource intensive) for 2021 – 2050. Under the climate change scenario, compared to the current state due to precipitation reduction the services for surface water regulation would be reduced by 6% in the recharge zone and 34% in the non-recharge zone. In addition, the services for the regulation of groundwater would be reduced by 19%. On the other hand, reduction of the precipitation would increase the soil protection services (23%). There would be very little increase of nitrate concentration or reduction of water quality services. The food supply services would increase by 5% because of increased field crop yield under irrigated water. Under the land use change scenarios, the ecosystems provided similar services to the climate change scenario except for the food provisioning services under the regional nature conservation scenario. Under this scenario, the food provisioning services would be reduced by 10%. The results indicate that the surface water and groundwater regulation is expected to decrease under future scenarios, whereas soil protection services are expected to increase because of the precipitation reduction. The food provisioning services would increase in the future scenarios except for the nature conservation scenario when a large area of agricultural land would be converted to forest land.

10) What is the state of ecosystem services in watersheds exporting to Israel?

Global trade in crop commodities enables countries with limited water and land resources to maintain food security, but it also makes them reliant on ecosystems abroad. The term ecosystem services (ES) represents the benefits people obtain from ecosystems. ES include food and feed provisioning, regulation of surface water, and protection of soils, among others. This study focuses on these three services that are considered key to maintaining food and water security. It looks at Israel as a case study, focusing on the staple crops wheat, maize, and soybean that are imported to Israel from the USA and Ukraine. Two watersheds were modeled in the USA, i.e., in Iowa (Little Sioux River) and Kansas (North and South Fork Solomon River), and one in Ukraine (Sula River) using also the Soil and Water Assessment Tool (SWAT). These watersheds represent a range of production systems, from a relatively low precipitation climate with wheat and irrigated corn production in western Kansas, to rainfed corn and soybean production in Iowa, and rainfed corn, soybean, and wheat production in Ukraine. Rather than using a simple indicator such as tons per hectare or cubic meters per second, we opted to use an index which is a normalized unitless value between 0 and 1. This enables us to compare watersheds of different sizes and streamflow quantities. On the other hand, indices introduce an extra layer of complexity and therefore uncertainty. The monthly streamflow is used to calculate a freshwater provisioning index based on an environmental flow requirement of 30% of long-term flow. The biomass and yield of the relevant crops are used to calculate the food provisioning index based on the maximum yield across all watersheds. The sediment yield is used to calculate the erosion regulation index based on a maximum tolerable soil loss rate of 5 t/ha per year. When comparing the three watersheds in terms of freshwater provisioning, the index is relatively high for all three cases (Ukraine 0.98; Iowa 0.95; Kansas 0.90). The erosion regulation index indicates 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 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.

References

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