The uneven water stress implications of global refugee migrations

Leonardo Bertassello
University of Notre Dame
Marc Müller (mmuller1@nd.edu)
University of Notre Dame https://orcid.org/0000-0001-6406-8184
Adam Wiechman
Arizona State University
Gopal Penny
Department of Civil and Environmental Engineering and Earth Sciences, University of Notre Dame
https://orcid.org/0000-0001-6628-1026
Marta Tuninetti
Polytechnic University of Turin https://orcid.org/0000-0003-2619-8783
Michèle Muller-Itten
University of Notre Dame

Article

Keywords:

Posted Date: March 7th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1318605/v1

The uneven water stress implications of global refugee migrations

Leonardo Bertassello[1], Marc F. Müller[1*], Adam Wiechman[1], Gopal Penny[1,2], Marta Tuninetti[3], and Michèle C. Müller-Itten[4]

[1]Department of Civil and Environmental Engineering and Earth Sciences, University of Notre Dame, Notre Dame, Indiana, USA
[2]Department of Geography, National University of Singapore, Singapore, Singapore
[3]Department of Environment, Land, and Infrastructure Engineering, Politecnico di Torino, Turin, Italy
[4]Department of Economics, University of Notre Dame, Notre Dame, Indiana, USA
[*]mmuller1@nd.ed

ABSTRACT

Millions displaced by conflicts have found refuge in water-stressed countries, where their perceived effect on water availability has shaped local water security discourses. We leverage new annual global data on the water footprint of food production to elucidate the effects of refugee displacement on host countries' water stress. The blue water demand transferred by refugees has nearly doubled between 2005 and 2016. It tends to be transferred towards countries with less water-intensive food provision systems, but more water-intensive dietary habits and comparably scarce water resources. Although minimal in most countries, implications on water stress can be dramatic in vulnerable countries that are already at risk of severe water crises. The 3.3 million refugees in Jordan may have contributed to water stress by up to 60%-points. We find that small changes to current UNHCR refugee resettlement goals can substantially ease the effect of refugee displacement on water stress in vulnerable countries.

Ensuring availability and sustainable management of water for all is a defining challenge of our time[1]. This is particularly true when recurring droughts collide with rapid demographic change and enduring armed conflicts[2]. Although almost never the sole cause of conventional wars[3,4], water scarcity may act as a risk factor for civil conflicts[5,6] and a possible linkage between climate change and violence[7]. However, armed conflicts also themselves affect water resources by damaging infrastructure and institutions, and disrupting prevailing local water uses[8]. Abandonment of irrigated agriculture in southern Syria during the recent civil war caused a near doubling of river flow volumes into downstream Jordan[9], suggesting that the impact of armed conflicts on water resources can propagate beyond borders, along international water ways. This effect on water availability is only half of the story, however, because the conflict also caused at least 1.1 million Syrian refugees to flee across the border into Jordan[10], adding pressure to the country's already scarce water resources[11]. By displacing water demand through refugee migration, conflicts can affect water resources beyond political and topographic boundaries.

As of 2021, approximately 80 million people are forcibly displaced by armed conflicts globally, more than 30 million of whom had to migrate internationally as refugees under UNHCR or UNWRA mandates or as asylum seekers (here jointly referred to as 'refugees'). The number of displaced refugees has nearly doubled from 12.1 to 23.1 million in the 2005-2016 period – the sharpest increase on record (see Figure S1 and Supplementary Information (SI)). The majority of displaced refugees during that period hail from countries in regions with arid or semi arid climates (Figure 1A), and nearly half of all refugees fled four particular countries or territories: Syria, Iraq, Palestine and Afghanistan (Figure 1B). The large majority (87%,[12]) of these migrants crossed into neighboring countries that share similar climate conditions and often already face their own substantial water availability challenges. A growing scholarship focuses on the water-security implications of migration in destination countries. Identified mechanisms include overburdened local infrastructure [e.g.,][]hussein2020syrian, jaafar2019refugees and the disruption of ecosystem services that support water provisioning, water distribution systems, flood management systems and safe drinking water[13]. These disruptions of water security can have dramatic socioeconomic consequences, for instance by affecting water prices and exacerbating preexisting economic inequalities and social divisions[2].

Yet the lion's share of a person's water consumption is embedded in the production of their food[14]. This notion is captured by the concept of per capita water footprint, which quantifies the volume of water necessary to produce, process and distribute a person's annual consumption[15]. Aggregated globally, this concept tracks the annual volume of water necessary to sustain humanity against the environmental limit of freshwater availability within which humanity can safely operate[16]. Water footprints can similarly be used to track countries' progress towards the Sustainable Development Goal dealing with water stress (indicator

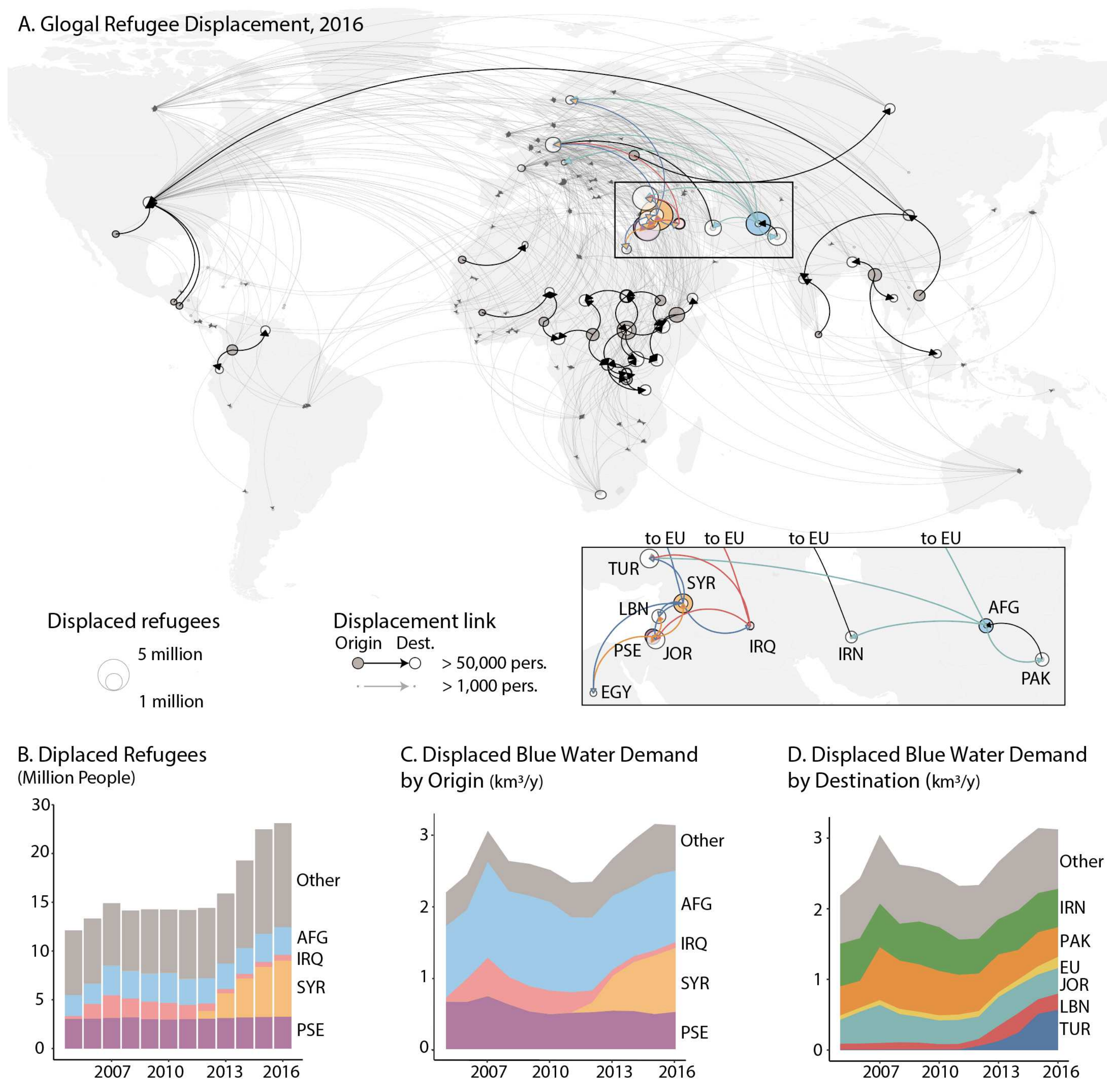

Figure 1. A. Origin and destination map of displaced refugees in 2016. Arrows indicate displaced populations of at least 1000 (grey) and 100,000 (black) people. **B.** Time series evolution of displaced refugees by country of origin. **C.** Displaced Blue Water Demand associated decreased food consumption in countries of origin. **D.** Displaced Blue Water Demand associated with long run increase in food demand in countries of refuge.

6.4.2)[17], although two important considerations are in order. First, per capita water footprints vary substantially across countries as determined by prevailing dietary habits and food supply systems[14]. Second, the water stress of a country is determined by water withdrawals within its territory. These withdrawals are *not* equivalent to the water footprint of its population. The global food trade network allows water to be withdrawn in one country to produce food that is consumed in another country[18]. These flows of 'virtual' water between the origin and destination countries of traded food affect the global distribution of water resources and the water stress of nations[19]. Similar virtual water flows can be associated with human movements (rather than traded goods) and have received much less research attention. Economic migrants have been shown to produce a flux of virtual water from the origin to destination country, as the former ramps up export-bound production to supply expatriate communities with homegrown goods[20]. The situation is different for refugees, however, because food production in their home country is often severely disrupted, causing water demand to increase in the destination countries of refugees. The amplitude of this effect and its local and global (through trade) repercussions on water stress remain to be characterized.

We leverage recent data on the water footprint of the production and international trade of 370 food products[21] to provide a first estimate of the refugee-related increase in water demand that drives these effects. By keeping track of the ultimate origin of the water embedded in traded goods, we elucidate the direct (migration) and indirect (trade) effect of refugee displacement on country-level water stress. The new water footprint dataset that we present captures these effects by uniquely distinguishing the effects of dietary habits, globalized supply chains, and agricultural water use efficiency. We find that the water footprint of refugee displacement ($\sim 24 km^3/y$ in 2016) is disproportionately carried by a small number of countries where implications on water stress can be substantial. These countries face water scarcity conditions that are comparable to the origin countries of refugees. They tend to have less water-intensive food provision systems but more water-intensive diets. They also tend to predominantly rely on local water resources for food production, meaning that the transfer of water demand associated with refugee displacement toward destination countries is not substantially relieved by global trade. Leveraging these results, we examine the potential for international resettlement plans to alleviate the unevenly distributed water burden of global refugee displacement.

Results

Global footprint

We estimate the long run water footprint of refugee displacement at nearly 24 $km^3 y^{-1}$ in 2016, a 175% increase since 2005 (Figure S2 in SI). This estimate was obtained by multiplying the number of displaced refugees by the per capita water footprint that we estimated for each destination country and each year (see Methods). It is approximately an order of magnitude smaller than that of economic migrants ($\approx 400 km^3 y^{-1}$) and about two orders of magnitude smaller than the volume of virtual water comprising global food trade ($\approx 2300 km^3 y^{-1}$). In per capita terms, the average water footprint of a refugee in circa 2010 was approximately half that of an economic migrant, and the two estimates bracket the global average (Table 1). This discrepancy reflects an important difference, which is that economic migrants not only have greater capacity for consumption but also tend to move to countries with greater consumption of water-intensive goods. In contrast, most refugee fluxes occur locally and connect countries with comparable (and lower than average) per capita water footprints.

Water footprint estimates in Table 1 include both rainfed and irrigated agriculture (but excludes the so-called grey water that would be necessary to assimilate the agriculture-related pollutants released into the environment). Yet the water security implications of the displaced water demand are, to a large extent, determined by the destination country's reliance on 'blue' water for irrigated agriculture. Blue water designates surface and groundwater resources that can be collected, stored, conveyed and used as a production factor. Because the water used to meet the increased irrigation demand prevents it from being used by other potential end-users, the associated opportunity costs are high and conducive to water competition[23,24]. In contrast, rain-fed agriculture relies on 'green' water supplied by rain and stored as soil moisture before being used by crops. This water could not have been used for other productive purpose and has little opportunity cost. We estimate the blue water demand (BWD) associated with refugee displacement for each country as the blue water embedded in the food produced in this country

	Refugees	Economic Migrants	Global Population
Pop. (ca. 2010)	10 M	200 M	6,900 M
WF per cap., home	892	1572	1385
WF per cap., dest.	1098	2064	-

Table 1. Per capita water footprint (WF) of migration in home and destination countries. Population and average per capita water footprint ($[m^3 \text{pers}^{-1} y^{-1}]$) for refugees (this study), economic migrants[20] and global population[22] in circa 2010. Water footprint estimates include blue and green water.

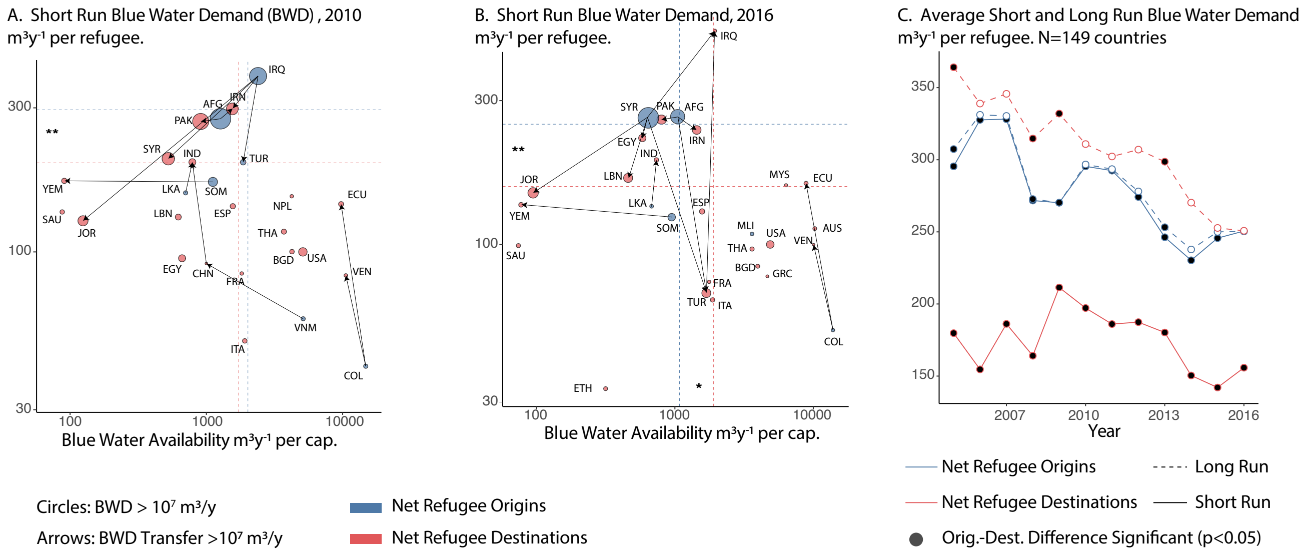

Figure 2. **A. and B.** Average per capita blue water availability (x-axis) and short-run blue water demand (y-axis) of refugees in their countries of origin (blue) and destination (red) in 2010 (**A**) and 2016 (**B**). Symbol sizes are proportional to the net BWD displaced by refugees the N=27 (2010) and N=30 (2016) countries with a net BWD larger than 0.01 km^3/y in absolute value. Arrows indicate BWD displacements larger than 0.01 km^3/y. Dashed lines indicate average axes values for origin (blue) and destination (red) countries, weighted by total net displaced BWDs (symbol sizes), with asterisks indicating statistically significant differences (p-values: $^{***} < 0.01 <^{**} < 0.05 <^{*} < 0.1$, obtained through bootstrapped t-tests with 1000 repetitions). **C.** Average per capita blue water demand per year across net origin (blue) and net destination (red) countries. Symbols represent weighted averages with net total displaced BWD as weights. Black symbols represents significant differences ($p < 0.05$) between origin and destination countries. Dashed and solid lines respectively represent short and long run results. Averages and t-tests in all panels were determined based on the full sample of N=149 countries of our dataset. They include the BWD that is both displaced directly (local production) and indirectly (trade).

but consumed by refugees anywhere. That is, it includes the direct BWD of refugees arriving in that country and the indirect BWD transferred via international food trade to refugees displaced elsewhere (see Methods). The BWD will be negative if refugees move out of the country, or if they move out of another country to which it exports food. Food also has an important cultural dimension and newly displaced refugees tend to maintain strong ties to their native foods and traditional diets[25,26]. Because of this, recent refugees will have a different consumption profile and per capita BWD than the local population, although this difference will likely attenuate with time as migrants adopt some of the cultural habits of their new home[27]. The per capita BWD of refugees will also differ from that of their peers in their home country, who might have a similar consumption profile but are supplied by a different food provision system. We uniquely disentangle the effects of dietary habits and food provision systems (see Methods). We estimate the short run BWD of refugees by combining the dietary habits of their origin country with the water intensity of the food provision system of their destination country. In contrast, the long run BWD associated refugees with both the food provision system and the dietary habits of their destination country. In line with the Sustainable Development Goals Indicator 6.4.2, we then estimate the effect of refugee migration on water stress in destination countries by taking the ratio between the displaced BWD (either long or short run) and the country's available water resources, that is the difference between the country's total renewable water resources and its environmental flow requirements[17].

Overall, we find that refugee fluxes are generally too small for refugees to significantly contribute to overall water stress in most destination countries. With a few important exceptions that will be discussed, the blue water demand corresponding to refugees account for less than 1% of total renewable water resource (net of environmental flow requirements) for most countries (see Table S2 in SI). There are, however, important differences between the food and water sectors of the origin and destination of refugee fluxes. We find that refugee displacement tends to transfer blue water demand towards countries with comparable levels of water availability but less water intensive food provision systems. Indeed, we find no significant difference between average per capita water availability in origin and destinations for most of the study period (Figure 2A, x-axis). The significant difference found in 2016 only appears twice in the 11 years period (Figure S3A in SI). Differences in food water intensity in origin and destination countries can be seen by considering differences in short run BWD (Figure 2AB, y-axis), which keep dietary habits constant. Refugees persistently move to destinations with less water intensive food provision systems throughout the study period (Figure 2C, dashed). This result is driven by refugees fleeing Iraq (before 2011, Figure 2A), Afghanistan and Syria (after 2011, Figure 2B). These three countries are the home countries of a sizeable portion of refugees and have some of the world's largest per capita BWD. However, the consumption profiles in destination countries have comparatively more water-intensive foods, so that the short term gains in water efficiency from refugees moving to countries with less water-intensive food provision systems are likely more than compensated by dietary changes in the long-run (Figure 2C, solid lines). Whether the blue water demand of incoming refugees translates into additional blue water withdrawals depends on the extent to which the destination country relies on in-kind food assistance or engages in global food trade. Such international transfers of virtual water can either alleviate water stress by distributing it from vulnerable countries outwards towards the global market[23,28,29] or, alternatively, propagate water demand to exacerbate tensions in already water stressed export countries[30,31]. We find that countries that produce or host the most refugees tend to rely on domestically sourced blue water for the large majority ($> 80\%$, Figure S3B in SI) of their food water needs, suggesting that international trade plays a limited role in alleviating or propagating any water stress associated with refugees. Regression results presented in Table S6 (in SI) suggest that reliance on virtual water import does not increase significantly with the number of refugees in destination countries. We were not able to include in-kind food assistance in the analysis, but discuss evidence in the Methods section that in-kind international food assistance is unlikely to have a significant effect on the per capita BWD of refugees.

Regional Impacts

The globally averaged results discussed above mask substantial variations between countries. One to two thirds of the blue water demand displaced by refugees on any given year during the 2005-2016 period can be traced back to conflicts in Afghanistan and Syria (Figure 1C) and the associated displacement of at least 8.8 million refugees from these two countries. More than 95% of the blue water demand associated with these two conflicts was transferred to six destination regions (Pakistan, Iran, Turkey, Lebanon, Jordan and the European Union, Figure 1D) with three distinct types of water stress implications.

The first group of countries have a large enough agriculture sector to accommodate the food water demand of refugees with no significant impact on country-level water stress. The majority of refugees displaced at the height of each crisis were hosted by Pakistan (1.9 million Afghans in 2010), Iran (1.0 million Afghans in 2010) and Turkey (2.8 Syrians in 2016). All three countries import very little food and rely heavily on domestically extracted blue water, with per capita blue water demands in the top 12% of the 173 countries in our dataset (see SI Figure S4). The blue water demand transferred by refugee displacement to each country is substantial and reaches 0.5 to 0.6 km^3 per year in the long run (Table 2). For comparison, this is approximately equivalent to half of the total annual volume discharged by the Jordan river under natural conditions[32]. Yet, in relative terms, the blue water demand displaced by refugees represents less than 0.5% of each country's available water resources and has a negligible effect on country-level water stress (Table 2). It is important to remember that these country-level outcomes overlook potentially large variations in the distribution of refugees within the destination countries. More than 80% of Afghan refugees in Pakistan settled in arid Khyber Pakhtunkwa and Balochistan provinces, which together account for less than 20% of the country's population and cropland (see SI Figure S6). The increased food demand is likely supplied by the (relatively) more blue-water-abundant Indus valley where the majority of Pakistan's irrigated cropland is located. Yet, unlike the virtual water embedded in food, the physical water used for the domestic needs of refugees (e.g., drinking and bathing) cannot be imported from more water-abundant parts of the country and has to be extracted locally, which can impose a significant strain on local infrastructure and water resources[33]. These challenges arise within broader water issues in Iran and Pakistan, which are both major exporters of blue water through global food trade amidst rapidly depleting groundwater resources[34,35]. Both countries are facing major water scarcity challenges[36,37] that are little affected by the food water demand of refugees.

Refugees have a similarly negligible impact on water stress in the second group of countries, this time due to their comparatively lower reliance on blue water for food. European food systems rely heavily on rain-fed agriculture with blue water only accounting for 5% of per capita food water footprints. The 1.1 million refugees from Syria and Afghanistan in the European Union (EU) countries by 2016 have only displaced about 0.062 km^3/yr of blue water demand towards the EU in the long run (Table 2). This is approximately 10 times smaller than that in Iran, Pakistan or Turkey for comparable fluxes of incoming refugees. In contrast to Iran and Pakistan, a substantial portion of European food is imported and does not deplete blue water resources within the continent. Therefore, although the political, cultural and socioeconomic implications of refugees in Europe are well documented[39,40], water stress associated with displaced food demand is unlikely to be a major issue.

In the third group of countries, however, migration causes a demand displacement that is sizable relative to water availability, and water stress implications can be dramatic. At least 1.2 and 1.1 million Syrians had respectively crossed into Lebanon and Jordan by 2016[10,38]. With substantial population of refugees even before the Syrian crisis, both countries have among the largest per capita concentrations of refugees in the world amidst high to very high water stress conditions (Figure S5). In Lebanon, one in four inhabitant was a refugee by 2016 (Table 2) and, although the country is historically water-abundant compared to the regional average, water stress has increased by 24 percentage points (from 35% to 59%) between 2005 and 2015[41]. We estimate that approximately one third (8.7 percentage points, Table 2, LBN) of this increase arises from the

Dest.	Pop. 10^6	Stress %	Refug. 10^6	Δ BWD MCM/y		Δ Stress %-points	
				SR	LR	SR	LR
IRN	73.8	81	1.0	305	595	0.4	0.8
PAK	179.4	115	1.9	514	627	0.4	0.5
TUR	79.8	42	2.8	204	534	0.2	0.6
EU	485.0	21	0.8	56	62	0.0	0.0
LBN	6.7	59	1.7	203	137	8.7	5.9
JOR	9.6	100	3.3	302	215	60.7	43.3
JOR*	9.6	100	1.1	171-18	138-18	17.6	10.6

Table 2. Population, water stress and number of refugees in Pakistan, Iran, Turkey, the European Union, Lebanon and Jordan. The estimated short (SR) and long (LR) displaced water demands (ΔBWD, in million cubic meters per year, note that $1km^3 = 1000MCM$) are given for each destination country, along with its effect on water stress (Δ Stress). PAK and IRN focus on 2010, at the height of the Afghan refugee displacement, and only include Afghan refugees – results including all refugee origins are provided in Table S2. Data for the EU are obtained for 2016 and include Afghan and Syrian refugees. LBN and JOR include refugees from Syria obtained from[10,38], which include unregistered refugees, and refugees from all other countries obtained from the UNHCR dataset for 2016. JOR* only includes registered and unregistered Syrian refugees from[10] and estimates the net effect of the Syrian refugee crisis on Jordanian water stress by subtracting the exploitable increase in transboundary river flow (18 MCM/y) from ΔBWD when determining $\Delta Stress$.

food-related short run BWD of displaced refugees. In Jordan, where refugees make up for nearly one third of the population, freshwater withdrawals already exceed available water resources and the country is facing a severe unfolding water crisis that is exacerbated by climate change[10,11]. Against that backdrop, we estimate that the food-related BWD of displaced refugees has increased water stress by approximately 43 to 61 percentage points in the long and short run, respectively (Table 2, JOR). For comparison, countries with *overall* water stress values beyond 40% are generally considered subject to high water stress[42].

Focusing on the subset of registered Syrian refugees in Jordan allows us to compare the demand- and supply-side effects of refugee displacement on water resources. On the demand side, we associate registered Syrian refugees in Jordan with a short run increase in blue water demand of 100 million cubic meters (MCM, $1km^3 = 1000MCM$) in 2016 and 85 MCM in 2015. Note that this is a conservative estimate because a substantial fraction of Syrian refugees in Jordan are unregistered. Approximately 40% of that increased demand was covered by food imports, mostly from Egypt, Saudi Arabia and Syria (Figure 3A), leaving a blue water demand of at least 51 MCM to be covered by Jordanian water resources in 2015 (Figure 3A, teal area). On the supply side, average Yarmouk river flow into Jordan has increased by about 50 MCM/yr between 2011 and 2015, compared to pre-2011 levels (Figure 3A, dashed). Approximately 55% of that increase can be attributed to abandoned irrigation agriculture in upstream Syria by fleeing refugees[9] (Figure 3A, dotted). Based on a comprehensive model of the Jordanian water sector[10], we estimate that approximately 80% (or 18 MCM) of the Yarmouk increase attributed to refugees was used by Jordanian agriculture in 2015 (see SI). This increase in blue water supply only offsets about 35% of the blue water demand associated with registered Syrian refugees in Jordan (Figure 3A, solid line vs. teal area). Overall, we estimate that refugee migration from the war in Syria has alone increased water stress in Jordan by approximately 11 to 18 percentage points (Table 2, JOR*).

The above discussion focuses on the blue water embedded in food and excludes the additional effect of domestic (drinking, cleaning, etc) water consumption. A recent estimate in Lebanon[38] associates Syrian and Palestinian refugees with a 20% increase in domestic water consumption and a 3 percentage point increase in country-level water stress. This increase adds on to the 8.7 percentage point increase in water stress that we found for the food water demand of refugees in Lebanon in the short run (Table 2, LBN). In Jordan, increased domestic water demand associated with Syrian refugees will, alone, cause an estimated 5.7 percentage point increase in the fraction of water-vulnerable households through the end of the century[10]. To be sure, the water challenges in Jordan and Lebanon predate the arrival of refugees who highlighted, rather than created, long-standing issues in both countries' water sectors. However, the water security implications of refugees have shaped the national discourse around water governance in both countries[43] and spurred social unrest. As Baylouny and Klingseis (2018)[44] put it, 'Syrian refugees, in effect, have been catalysts of domestic conflict over water security, providing one spillover from Syria's civil war.

Refugee Resettlement

Our analysis has shown that the water stress of refugee displacement is disproportionately borne by a few countries hosting an incommensurate number of refugees amidst severe preexisting water security challenges. Relocating a portion of these refugees towards less water-stressed destination countries stands out as a sensible means to lift some of the burden and curtail potentially emerging water crises.

Ongoing resettlement activities conducted by UNHCR are a mechanism by which international protection can be provided for refugees who are either at risk in their country of refuge or have particular needs or vulnerabilities (associated with, e.g., their gender or age,[45]). Resettlement is also a means to provide a durable solution for refugees based on a comprehensive needs assessment[45]. UNHCR identified approximately 1.44 million refugees in need of resettlement[46]. These refugees are preeminently currently displaced in Turkey, Uganda, Lebanon and Ethiopia (Figure 3B (i), pie). Using our blue water demand values for 2016, we estimate that resettling these refugees to water-abundant countries in Europe or North America would alleviate approximately 99.7 MCM of blue water demand in the current countries of refuge, but (only) decrease water stress by at most 2 percentage points (Figure 3B (i), bars).

The 1.44 million refugees of the current resettlement plan were determined to be most in need of relocation based on their individual circumstances. In other words, resettling this particular group of refugees is expected to allow the largest overall decrease in the average individual hardship faced by refugees. This implies that any alternative distribution of resettlement candidates across current countries of refuge (here referred to as 'resettlement plan') that might relieve more water stress will invariably relieve *less* of the individual hardship faced by the refugees. We characterize this trade-off by identifying the set of resettlement plans that are Pareto optimal, in the sense that no alternative resettlement plan is simultaneously more advantageous in terms of relieving both the individual hardship of refugees and the water stress of the refuge countries. In that process, we assume that the (to us) unobserved inclusion criterion used by UNHCR in their current resettlement plan is based on the circumstances faced by individual refugees, rather than the burden carried by the current countries of refuge[45] (see Methods). We find that resettlement plan that is more than 85% similar to the current UNHCR plan (i.e., approximately 200,000 of the 1.44M refugees of the plan would be resettled out of Jordan and Lebanon instead of Turkey, Uganda, Ethiopia and Iran) would double average relief of water stress in current countries of refuge, while decreasing the average relief of individual hardship (expressed as the waiting time to resolution, see Methods) by about 5 percent (Figure 3B, ii). Moving further towards the right on Figure 3C puts an increasing relative weight on water stress relief compared to individual hardship. Refugees are successively increasingly relocated out of Jordan, Lebanon (beyond Figure 3B, iii) and Yemen (beyond Figure 3B, iv), which are the three current countries of refuge in the UNHCR resettlement plan where refugees have a measurable (>2 percentage points) impact on water stress. At the extreme, a resettlement plan designed specifically to maximize the relief of average water stress would focus almost exclusively on these three countries, where it would relieve water stress by a cumulative 16.4 percentage points (Figure 3B, v). However, it would only be 37% as effective as the current UNHCR plan in terms of relieving the individual hardship of refugees.

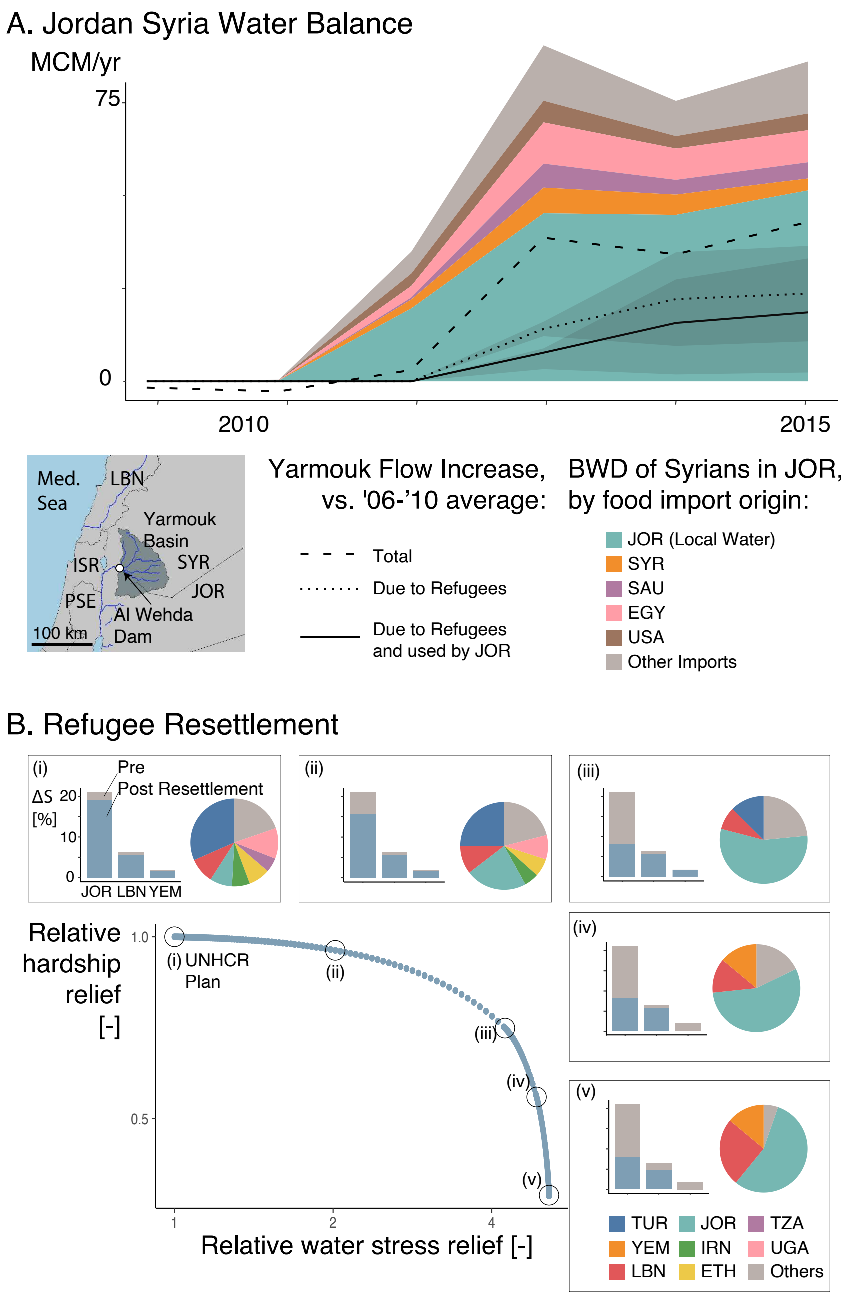

Figure 3. A. Changes in the annual flow volume of the Yarmouk river compared to 2006-2010 average. Black lines respectively indicate the observed flow changes at Al Wehda dam on the Syria-Jordan border (dashed), the estimated portion of that change attributable to abandoned Syrian agriculture (dotted) and the portion of the refugee-attributed flow increase that was likely retrieved for Jordanian irrigation (plain), with shaded area indicating approximate confident ranges (see SI). Stacked colors indicate the blue water demand of Syrian refugees displaced into Jordan. Approximately 60% of this water is not procured through food import but sourced domestically by Jordan. **B.** Refugee resettlement trade-off between relieving the individual hardship of refugees and the water stress of the countries of refuge. Dots in the main graph represent alternative resettlement plans, where the 1.44 million refugees in the current UNHCR plan (i) are selected from alternative combinations of current refuge countries. Pie charts represent the composition of the highlighted plans. Bar charts represent water stress associated with refugees in Jordan, Lebanon and Yemen without resettlement (gray) and with (blue) each highlighted plan. Water stress values without resettlement in Jordan and Lebanon are computed using literature values for registered and unregistered Syrian refugees[10,38] and UNHCR-reported numbers of non-Syrian registered refugees. We exclude Palestinian refugees under UNRWA mandate and do not account for supply-side effects of refugee migration on transboundary streamflow into Jordan. On the main graph, an increasing weight is attributed to water stress relief compared to individual hardship relief as one moves from the current UNHCR plan (i) towards plan (v), which is entirely determined based on water stress relief.

Conclusion

While illustrative of the potential for using BWD estimates to inform policy, the above analysis on refugee resettlement should be seen in its proper context. Global refugee displacement is a complex multi-dimensional crisis that is upending the life of millions of real humans. The two-dimensional trade-off represented in Figure 3B does not come close to capturing the myriad of challenges faced by the refugees themselves, and by the countries in which they find refuge. Our results have shown that, reassuringly, in the overwhelming majority of cases, water stress associated with food water demand in the countries of refuge is not a major issue. In a few specific countries, however, the added water demand associated with refugees has the potential to destabilize an already stressed water sector and have potentially dramatic water- and food-security consequences. Because of this, relatively small changes in current resettlement plans can have a potentially outsize benefit in terms of relieving the water stress of refuge countries. Nevertheless, weighing the individual hardships faced by refugees against the collective burden shouldered by the refuge countries is a thorny endeavor. Currently, UNHCR explicitly states that 'resettlement should not be pursued because individual refugees have become a burden ([45], p. 245). However, the hardship faced by refugees is likely determined, to a certain extent, by the ability of the country of refuge to accommodate them. Whether, and to what extent, this ability should be accounted for in refugee resettlement processes is, at the end of the day, a political and ethical decision that can be informed by the Pareto optimization framework that we describe.

Ultimately, it is important to remember that less than 40,000 of the 1.44 million refugees in need of resettlement had been successfully relocated by 2020[46]. Increased pledges by higher income countries to welcome the remaining refugees in the current UNHCR resettlement plan would have relieved some of the water stress in the most vulnerable countries of refuge, *in addition to* the intended relief of personal hardship. There is an urgent need for the international community to step up and support the resettlement effort, in order to relieve both the individual hardship of refugees and the burden shouldered by the countries giving them refuge.

Methods

Data Availability

The dataset produced in this study is openly available at [REPOWILLBEADDEDUPONACCEPTANCE].

Refugees

Refugee displacement matrices R_{od}^{y} were constructed using UNHCR data (freely available at https://www.unhcr.org/refugee-statistics/) and represent the number of refugees and asylum seekers from country o living in country d on year y. The dataset includes refugees under UNHCR and UNRWA mandates, but excludes internally displaced persons and unregistered international refugees. Although internally displaced persons outnumber international refugees by nearly two to one[12], we excluded them from the analysis because they do not cause direct international water demand displacement through migration. The portion of international refugees that are not registered with a UN agency is also likely substantial. Approximately 1.1 and 1.2 million Syrian refugees have respectively been reported in Jordan[10] and Lebanon[38] in 2016, of whom 0.65 and 1.0 million (respectively) are registered and included in UNHCR data. For these two countries where the information is available, we included unregistered refugees in country-specific results when indicated (i.e. Table 2 and baseline refugee-induced water stress in Figure 3C).

Focusing on the 2005-2016 period for consistency with the virtual water data set, we removed countries hosting (or supplying) less than 1000 refugees in all 11 years of the period. The remaining set of 167 countries and autonomous regions that contributed meaningfully to global refugee migration during that period were included in the analysis. Data limitations prevented us from determining food water demand or water stress conditions for 29 of these countries (see Table S1). The water demand transfers associated with refugees originating from these countries was estimated in an identical way than for refugees that are stateless or of unknown origin. Namely, the short range per capita water demand of refugees from these countries in their countries of destination was approximated as the weighted average of the corresponding values of all other refugees migrating into the same country. The long range per capita water demand is solely determined by the country of destination and not affected by the missing water data in the country of origin. However, we were not able to determine the water demand transfer associated with refugees migrating *into* the 29 countries with missing water data. The approximately 3% of global refugees migrating into these countries (Table S1) were therefore excluded from the analysis.

Long-run food water demand

The water footprint of primary and processed crops were obtained from the CWASI dataset[21] (freely available at https://www.watertofood.org/download/). The dataset combines FAO trade data with a model estimating the crop-specific water requirement on production sites in the countries where the food was produced[47,48]. Unlike previous data, water footprint estimates are provided *yearly* between 1961 and 2016, based on the assumption that the variability of crop water footprint is driven by variations in crop yields[49]. The dataset provides the blue and green water (or virtual' water) embedded in the production and international trade of 370 raw and processed foods. The dataset excludes grey water needed to dissolve the pollutants associated with food production. Grey water makes up a non-negligible portion ($\approx 9\%$,[22]) of the water footprint of global food production but is challenging to accurately estimate [**?**, e.g.,]]gil2017uncertainty,de2019improving. We processed the data as detailed in SI to obtain $C_{dk}^{(y)}$, the per-capita (blue or total) water footprint of food type k consumed (though not necessarily produced) in country d on year y. We also computed $X_{pdk}^{(y)}$, the fraction of the virtual water (blue or total) in food type k consumed in country d that ultimately originates from country p through international food trade (see SI). The food water demand (blue or total) in country p of a native person consuming food in country d in year y is then:

$$\Omega_{odp,\mathsf{LR}}^{(y)} = \sum_k C_{dk}^{(y)} X_{pdk}^{(y)} \tag{1}$$

Note that the index p represents the country, where the water embedded in the consumed food was obtained. It can be differing from the country of refuge d because of international food trade. Equation 1 represents the long run per capita water demand in refuge country d of refugees from *any* country o. It assumes that the consumption habits of refugees are indistinguishable from that of the native population in the country of refuge after a sufficiently long period of time.

Short-run food water demand

This assumption might not hold over shorter time horizons, where the per capita water demand of refugees might differ substantially from that of the native population. Assuming that newly arrived refugees will preserve dietary habits from their country of origin o but consume food obtained in their country of refuge d, the short-run food water demand in country p of a refugee from country o that lives in country d can be expressed as:

$$\Omega_{odp,\mathsf{SR}}^{(y)} = \sum_k D_{ok}^{(y)} W_{dk}^{(y)} X_{pdk}^{(y)} \tag{2}$$

where $D_{ok}^{(y)}$ denotes the mass (ton) of good k that refugee would have consumed in their country of origin o. To estimate that value, we used country-level food production, trade and stock variations from the Food and Agricultural Organization (FAO) food balance sheets as described in SI. In Equation 2, $W_{dk}^{(y)}$ denotes the virtual water content (m^3 of virtual water per ton) of food k obtained by the refugees in their country of refuge.

We were not able to obtain globally consistent data on in-kind food assistance that covers the 2005-2016 period and so make the assumption that the water intensity $W_{dk}^{(y)}$ of the food consumed by the refugee is identical to that of the local population in their country of refuge. Because international food assistance attenuates refugees' reliance on locally produced food, neglecting it might cause us to overestimate the short run impact of refugees on the water stress of destination countries. However, we do not believe that this overestimation is substantial for two reasons. First, one half[50] to three quarter[51] of refugees do not live in refugee camps and so are less likely to be reached by in kind food assistance, which has rapidly been phased out over the last 20 years and replaced by cash assistance[52]. Second, a non-negligible portion of food rations are sold into the black market. Evidence from refugee camps in Kenya[53] and Rwanda[50] suggest that nearly all refugees sell part or most of their food allotment on the black market to buy food that conforms with their traditional dietary habits (thus creating a sense of normalcy[53]). Ethnographic data from Kakuma camp in Kenya[54], suggest that the 80% of refugees with access to cash (through employment or remittance) sold nearly all their relief package into the black market. The remaining 20% who depend almost wholly on relief packages still sold nearly 50% of their allotment to traders. These finding suggest that even refugees benefiting from in kind food assistance are likely to procure a substantial part of their food from the same sources as native inhabitants. In other words, $W_{dk}^{(y)}$ is unlikely to be substantially different between refugees and the local population.

Even assuming identical $W_{dk}^{(y)}$ for refugees and locals, in-kind food aid is excluded from the international trade data used in this analysis. If the virtual water imported through in-kind food aid is substantial compared to the country's water footprint of food consumption, this can introduce a non negligible error on $W_{dk}^{(y)}$. However, the virtual water (blue, green and grey) imported through in-kind food aid reported in Ref[55] remains below 9% of the water footprint of the national consumption of crop products[56] for the 9 receiving countries that count for 2% or more of the global water footprint of food aid (Table S3). This suggests that the effect of in kind food aid on the average virtual content of food in destination countries is not substantial.

Displaced blue water demand and water stress

The blue water demand transferred into (or out of) country p by the food consumption of refugees displaced from country o into country d on year y is expressed as:

$$\Delta BWD_{odp,\mathsf{SR\ or\ LR}}^{(y)} = R_{od}^{y} \cdot \Omega_{odp,\mathsf{SR\ or\ LR}}^{(y)} \tag{3}$$

If $p = d$, this represents the increased demand on the local water resources of the country of refuge d. If $p \neq d$, Equation 3 represents the water embedded in increased food export from a third country p associated with increased food demand in the country of refuge d. Note that $\Delta BWD^{(y)}_{odp,\text{SR or LR}}$ can be negative if refugee displacement decrease water demand in country p, either because refugees migrate out of p (i.e. $p = o$) or because p is a major exporter of food to o. Accordingly, the aggregate blue water demand transferred by refugees moving out of o (to any destination, Figure 1C) or into d (from any origin, Figure 1D) are respectively expressed as:

$$\Delta BWD^{(y)}_{o,\text{SR or LR}} = \sum_d \sum_p R^y_{od} \cdot \Omega^{(y)}_{odp,\text{SR or LR}} \tag{4}$$

$$\Delta BWD^{(y)}_{d,\text{SR or LR}} = \sum_o \sum_p R^y_{od} \cdot \Omega^{(y)}_{odp,\text{SR or LR}} \tag{5}$$

Similarly, the blue water demand transferred into country p by global refugee displacement (from any origin or destination, Figure 2A) is expressed as:

$$\Delta BWD^{(y)}_{p,\text{SR or LR}} = \sum_o \sum_d R^y_{od} \cdot \Omega^{(y)}_{odp,\text{SR or LR}} \tag{6}$$

All above expressions can be similarly used for total water footprints (Figure 1C and Table 1) by replacing the per capita blue water demands ($\Omega_{odp,\text{SR or LR}}$) by the *sum* of blue and green water demands.

In line with the UN SDG indicator 6.4.2, we define blue water availability as the difference between total renewable water resources (TRWR) and environmental flow requirements (EFR), which we normalize by the country's population size to obtain per capita blue water availability displayed in Figure 2A and 2B. SDG indicator 6.4.2 then defines water stress in country p on year y as the ratio between total freshwater withdrawals (TFWW) and blue water availability[57]:

$$S^{(y)}_p = \frac{TFWW^{(y)}_p}{TRWR^{(y)}_p - EFR^{(y)}_p} \tag{7}$$

We extend this framework to evaluate the change in water stress due to the increased (or decreased) blue water demand associated with global refugee displacements:

$$\Delta S^{(y)}_{p,\text{SR or LR}} = \frac{\Delta BWD^{(y)}_{p,\text{SR or LR}} \cdot \frac{1}{e^{(y)}_p}}{TRWR^{(y)}_p - EFR^{(y)}_p} \tag{8}$$

where e represents irrigation efficiency, which is necessary to relate the gross water use metric in the water stress indicator (TFWW) to the net water consumption metric (ΔBWD) obtained in our analysis. Following Ref[58], we estimated e as the ratio between a country's irrigation water requirements (IWR) and its irrigation water withdrawal (IWW). All above country level metrics (population, TFWW, TRWR, EFR, IWR and IWW) were obtained from the FAO AQUASTAT database (openly available at `https://www.fao.org/aquastat/en/`) and linearly interpolated to obtain annual estimates. We used agricultural water withdrawals for countries with no IWW estimates[58], and set $EFR = 0$ for the 10 (mostly arid) countries with no provided value (Table S2). Countries without data for any of the other metrics were excluded from the analysis (see Table S2).

Refugee Resettlement

Refugee resettlement decisions entail a trade-off between relieving the individual hardship faced by the refugee themselves, and relieving water stress in the countries currently hosting them. To characterize this trade off, we express the short run effect of a marginal refugee on the water stress conditions in their country of refuge d as:

$$\Delta S'^{(y)}_{d,\text{SR}} = \frac{\sum_o \Omega^{(y)}_{odd,\text{SR}} \cdot \frac{1}{e^{(y)}_d}}{TRWR^{(y)}_d - EFR^{(y)}_d} \tag{9}$$

In other words, we assume that all refugees moving into country d (no matter their origin) have an identical marginal blue water demand that is equal to their average per capita blue water demand in their country of refuge. We compute $\Delta S'^{(y)}_{d,\text{SR}}$ for 2016 (the last year the CWASI dataset) and use it as a proxy for its value in 2020 (the year of the considered resettlement plan).

The opposite side of the trade-off – the hardship of individual refugees – is challenging to fathom, let alone to represent within an analytical model. Here, we assume that each refugee is waiting for resolution of hardship, but some longer than others. Within each country d, resolutions occur independently at a known average rate λ_d, so that the waiting time t (hereafter 'individual hardship') follows an exponential distribution across the refugee population (i.e. resolutions within each country of refuge follow a Poisson process),

$$t \sim exp(\lambda_d). \tag{10}$$

The rate parameter λ_d captures the capacity of the current country of refuge to respond to refugee needs. As researchers, we observe neither λ_d nor the refugee's individual hardship t, but we assume that with access to case files and better on-the-ground information, the UNHCR is able to identify the individuals with the biggest hardship, and recommends those above some threshold $\tilde{t}$ for resettlement. This threshold is identical across countries in order for resettlement to minimize the overall hardship of refugees across countries.

We show in SI that we can infer λ_d from the fraction of refugees selected for resettlement in each current country of refuge,

$$\lambda_d = \ln R_d - \ln x_d^{\mathsf{UN}} \tag{11}$$

where x_d^{UN} and R_d are respectively the number of refugees reallocated from country d under the current resettlement plan (obtained for 2020 from Ref[46]), and the total number of registered refugees under UNHCR mandate in that country (obtained for 2020 from `https://www.unhcr.org/refugee-statistics/`)).

Once the parameters for the hardship distributions identified for each current country of refuge, we can compute the remaining individual hardship for any alternative resettlement plans. Formally, let the vector $\mathbf{x}$ represent a resettlement plan, with each term representing the number x_d of refugees resettled out of each current country of refuge d. For simplicity, we assume that a resettled refugee no longer experiences hardship and adds no water stress to the destination country. This assumption is approximately correct because resettlement destinations are generally water-rich high-income countries (e.g., the EU in Table 2), see Ref[?]. We assume that an alternate resettlement plan is feasible if it requires no more hosting capacity than the current plan, i.e. $\sum_d x_d \leq \sum_d x_d^{\mathsf{UN}}$. Using the approach outlined in SI, we identify the feasible plans that maximize a weighted average between the following two objectives:

(i) The aggregate relief of the individual hardship of refugees. Assuming that hardship is exponentially distributed across the refugees of each current country of refuge d, this corresponds to:

$$\Delta\tau(\mathbf{x}) = \sum_d \int_0^{x_d} -\frac{1}{\lambda_d} \ln \frac{x}{R_d} dx \tag{12}$$

(ii) The aggregate relief of the water stress of current countries of refuge:

$$\Delta S'(\mathbf{x}) = \sum_d x_d \Delta S'^{(y)}_{d,\mathsf{SR}} \tag{13}$$

Each such plan is Pareto-optimal, in the sense that they cannot be simultaneously improved upon for both criteria of the optimization. Figure 3B shows five candidate plans (i) - (v), along with the relief $\Delta\tau(\mathbf{x})/\Delta\tau(\mathbf{x}^{\mathsf{UN}})$ and $\Delta S'(\mathbf{x})/\Delta S'(\mathbf{x}^{(v)})$. This Pareto-frontier illustrates the tradeoff between relieving the individual hardship of refugees and the collective water stress of the countries of refuge.

References

1. United Nations, U. Transforming our world: The 2030 agenda for sustainable development. *Resolut. adopted by Gen. Assembly* (2015).
2. Borgomeo, E. *et al.* Tackling the trickle: ensuring sustainable water management in the arab region. *Earth's Futur.* (2020).
3. Wolf, A. T. "water wars" and water reality: conflict and cooperation along international waterways. In *Environmental change, adaptation, and security*, 251–265 (Springer, 1999).
4. Dell'Angelo, J., D'Odorico, P. & Rulli, M. C. The neglected costs of water peace. *Wiley Interdiscip. Rev. Water* **5**, e1316, DOI: 10.1002/wat2.1316 (2018). https://onlinelibrary.wiley.com/doi/pdf/10.1002/wat2.1316.
5. Gleick, P. H. Water, drought, climate change, and conflict in syria. *Weather. Clim. Soc.* **6**, 331–340 (2014).
6. Gizelis, T.-I. & Wooden, A. E. Water resources, institutions, & intrastate conflict. *Polit. Geogr.* **29**, 444–453 (2010).

7. Roche, K. R., Müller-Itten, M., Dralle, D. N., Bolster, D. & Müller, M. F. Climate change and the opportunity cost of conflict. *Proc. Natl. Acad. Sci.* (2020).

8. Gleick, P. H. Water as a weapon and casualty of armed conflict: A review of recent water-related violence in iraq, syria, and yemen. *Wiley Interdiscip. Rev. Water* **6**, e1351 (2019).

9. Müller, M. F., Yoon, J., Gorelick, S. M., Avisse, N. & Tilmant, A. Impact of the syrian refugee crisis on land use and transboundary freshwater resources. *Proc. national academy sciences* **113**, 14932–14937 (2016).

10. Yoon, J. *et al.* A coupled human–natural system analysis of freshwater security under climate and population change. *Proc. Natl. Acad. Sci.* **118** (2021).

11. Rajsekhar, D. & Gorelick, S. M. Increasing drought in jordan: Climate change and cascading syrian land-use impacts on reducing transboundary flow. *Sci. advances* **3**, e1700581 (2017).

12. United Nations High Commission for Refugees. Global trends – forced displacement in 2016. *UNHCR, Geneva* (2017).

13. Wrathall, D. J., Hoek, J., Walters, A., Devenish, A. *et al.* Water stress and human migration: a global, georeferenced review of empirical research. *FAO Land Water Discuss. Pap.* (2018).

14. Vanham, D. *et al.* Water consumption related to different diets in mediterranean cities. *Sci. Total. Environ.* **573**, 96–105 (2016).

15. Hoekstra, A. Y. & Hung, P. Q. Globalisation of water resources: international virtual water flows in relation to crop trade. *Glob. environmental change* **15**, 45–56 (2005).

16. Vanham, D. *et al.* Environmental footprint family to address local to planetary sustainability and deliver on the sdgs. *Sci. Total. Environ.* **693**, 133642 (2019).

17. Vanham, D. *et al.* Physical water scarcity metrics for monitoring progress towards sdg target 6.4: An evaluation of indicator 6.4. 2 “level of water stress”. *Sci. total environment* **613**, 218–232 (2018).

18. Konar, M. *et al.* Water for food: The global virtual water trade network. *Water Resour. Res.* **47** (2011).

19. D’Odorico, P. *et al.* Global virtual water trade and the hydrological cycle: patterns, drivers, and socio-environmental impacts. *Environ. Res. Lett.* **14**, 053001 (2019).

20. Metulini, R., Tamea, S., Laio, F. & Riccaboni, M. The water suitcase of migrants: Assessing virtual water fluxes associated to human migration. *PloS one* **11** (2016).

21. Tamea, S., Tuninetti, M., Soligno, I. & Laio, F. Virtual water trade and water footprint of agricultural goods: the 1961–2016 cwasi database. *Earth Syst. Sci. Data* **13**, 2025–2051 (2021).

22. Hoekstra, A. Y. & Mekonnen, M. M. The water footprint of humanity. *Proc. national academy sciences* **109**, 3232–3237 (2012).

23. Konar, M., Dalin, C., Hanasaki, N., Rinaldo, A. & Rodriguez-Iturbe, I. Temporal dynamics of blue and green virtual water trade networks. *Water Resour. Res.* **48** (2012).

24. Chiarelli, D. D. *et al.* Competition for water induced by transnational land acquisitions for agriculture. *Nat. Commun.* **13** (2022).

25. Mary Story PhD, R. & Harris, L. J. Food habits and dietary change of southeast asian refugee families living in the united states. *J. Am. Diet. Assoc.* **89**, 800–801 (1989).

26. Moffat, T., Mohammed, C. & Newbold, K. B. Cultural dimensions of food insecurity among immigrants and refugees. *Hum. Organ.* **76**, 15–27 (2017).

27. Wilson, A. & Renzaho, A. Intergenerational differences in acculturation experiences, food beliefs and perceived health risks among refugees from the horn of africa in melbourne, australia. *Public health nutrition* **18**, 176–188 (2015).

28. D’Odorico, P. *et al.* Global virtual water trade and the hydrological cycle: patterns, drivers, and socio-environmental impacts. *Environ. Res. Lett.* **14**, 053001, DOI: 10.1088/1748-9326/ab05f4 (2019).

29. Dalin, C., Konar, M., Hanasaki, N., Rinaldo, A. & Rodriguez-Iturbe, I. Evolution of the global virtual water trade network. *Proc. Natl. Acad. Sci.* **109**, 5989–5994 (2012).

30. Dell’Angelo, J., D’Odorico, P. & Rulli, M. C. The neglected costs of water peace. *Wiley Interdiscip. Rev. Water* **5**, e1316 (2018).

31. Suweis, S. *et al.* Structure and controls of the global virtual water trade network. *Geophys. Res. Lett.* **38** (2011).

32. UN-ESCWA and BGR (United Nations Economic and Social Commission for Western Asia; Bundesanstalt für Geowissenschaften und Rohstoffe). Chapter 6: Jordan river basin. *Inventory of Shared Water Resources in Western Asia. Beirut* (2013).

33. Faruqui, N. I. Responding to the water crisis in pakistan. *Int. J. Water Resour. Dev.* **20**, 177–192 (2004).

34. Dalin, C., Wada, Y., Kastner, T. & Puma, M. J. Groundwater depletion embedded in international food trade. *Nature* **543**, 700–704 (2017).

35. Rosa, L., Chiarelli, D. D., Tu, C., Rulli, M. C. & D'Odorico, P. Global unsustainable virtual water flows in agricultural trade. *Environ. Res. Lett.* **14**, 114001 (2019).

36. Watto, M. A. & Mugera, A. W. Groundwater depletion in the indus plains of pakistan: imperatives, repercussions and management issues. *Int. J. River Basin Manag.* **14**, 447–458 (2016).

37. Noori, R. *et al.* Anthropogenic depletion of iran's aquifers. *Proc. Natl. Acad. Sci.* **118** (2021).

38. Jaafar, H., Ahmad, F., Holtmeier, L. & King-Okumu, C. Refugees, water balance, and water stress: Lessons learned from lebanon. *Ambio* **49**, 1179–1193 (2020).

39. Liebe, U., Meyerhoff, J., Kroesen, M., Chorus, C. & Glenk, K. From welcome culture to welcome limits? uncovering preference changes over time for sheltering refugees in germany. *PloS one* **13**, e0199923 (2018).

40. Bansak, K., Hainmueller, J. & Hangartner, D. How economic, humanitarian, and religious concerns shape european attitudes toward asylum seekers. *Science* **354**, 217–222 (2016).

41. FAO. Aquastat core database. *Food Agric. Organ. United Nations.* **5** (2020). Accessed on 01.07.2021.

42. Hanasaki, N., Yoshikawa, S., Pokhrel, Y. & Kanae, S. A quantitative investigation of the thresholds for two conventional water scarcity indicators using a state-of-the-art global hydrological model with human activities. *Water Resour. Res.* **54**, 8279–8294 (2018).

43. Hussein, H., Natta, A., Yehya, A. A. K. & Hamadna, B. Syrian refugees, water scarcity, and dynamic policies: how do the new refugee discourses impact water governance debates in lebanon and jordan? *Water* **12**, 325 (2020).

44. Baylouny, A. M. & Klingseis, S. J. Water thieves or political catalysts? syrian refugees in jordan and lebanon. *Middle East Policy* **25**, 104–123, DOI: https://doi.org/10.1111/mepo.12328 (2018). https://onlinelibrary.wiley.com/doi/pdf/10.1111/mepo.12328.

45. UNHCR. Unhcr resettlement handbook and country chapters. *Chapter six: UNHCR Resettl. Submiss. Categ.* (2018).

46. UNHCR. Unhcr projected global resettlement needs 2020. *25th Annu. Tripart. Consult. on Resettl.* (2019).

47. Allen, R. G., Pereira, L. S., Raes, D., Smith, M. *et al.* Crop evapotranspiration-guidelines for computing crop water requirements-fao irrigation and drainage paper 56. *Fao, Rome* **300**, D05109 (1998).

48. Mekonnen, M. M. & Hoekstra, A. Y. The green, blue and grey water footprint of crops and derived crop products. *Hydrol. Earth Syst. Sci.* **15**, 1577–1600 (2011).

49. Tuninetti, M., Tamea, S., Laio, F. & Ridolfi, L. A fast track approach to deal with the temporal dimension of crop water footprint. *Environ. Res. Lett.* **12**, 074010 (2017).

50. Taylor, J. E. *et al.* Economic impact of refugees. *Proc. Natl. Acad. Sci.* **113**, 7449–7453 (2016).

51. Refugee camps: Definition, facts and statistics.

52. Food assistance: cash and in-kind.

53. Oka, R. C. Coping with the refugee wait: The role of consumption, normalcy, and dignity in refugee lives at kakuma refugee camp, kenya. *Am. Anthropol.* **116**, 23–37 (2014).

54. Oka, R. Unlikely cities in the desert: the informal economy as causal agent for permanent" urban" sustainability in kakuma refugee camp, kenya. *Urban Anthropol. Stud. Cult. Syst. World Econ. Dev.* 223–262 (2011).

55. Jackson, N., Konar, M. & Hoekstra, A. Y. The water footprint of food aid. *Sustainability* **7**, 6435–6456 (2015).

56. Mekonnen, M. M. & Hoekstra, A. Y. National water footprint accounts: the green, blue and grey water footprint of production and consumption. volume 2: appendices. *Daugherty Water for Food Glob. Institute: Fac. Publ.* **84** (2011).

57. Vanham, D. *et al.* Physical water scarcity metrics for monitoring progress towards SDG target 6.4: An evaluation of indicator 6.4.2 "Level of water stress". *Sci. Total. Environ.* **613-614**, 218–232, DOI: 10.1016/j.scitotenv.2017.09.056 (2018).

58. Frenken, K. & Gillet, V. Irrigation water requirement and water withdrawal by country. Tech. Rep., FAO AQUASTAT (2012).

Acknowledgements

We thank Drs Ilaria Schnyder von Wartensee, Diogo Bolster and Rahul Oka for their helpful ideas and feedback. We thank Dr Jim Yoon for his help on the Jordan case study. L.B., G.P., M.C.M-I and M.F.M acknowledge support from the National Science Foundation (NSF) Coupled Natural Systems Human (CNH) program award ICER 1824951.

Author contributions statement

M.F.M and M.C.M-I designed research; L.B., A.W., M.T. and G.P. performed the analysis; M.F.M. and L.B. wrote the paper.

Additional information

Competing interests Authors declare no conflict of interest.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- VWSyria6.pdf