ENVIRONMENTAL RESEARCH
LETTERS

PURPOSE-LED PUBLISHING™

Part of the ENVIRONMENTAL RESEARCH SERIES

LETTER • OPEN ACCESS

Food security beyond borders: how crop imports affect drought risk of conflict-affected countries

To cite this article: Henrique M D Goulart *et al* 2025 *Environ. Res. Lett.* **20** 124007

ENVIRONMENTAL RESEARCH
LETTERS

OPEN ACCESS

RECEIVED
23 June 2025

REVISED
21 October 2025

ACCEPTED FOR PUBLICATION
5 November 2025

PUBLISHED
21 November 2025

LETTER

Food security beyond borders: how crop imports affect drought risk of conflict-affected countries

Henrique M D Goulart[1,2,*], **Raed Hamed**[2], **Rick J Hogeboom**[3,4,*], **Karen Meijer**[5] **and Ruben Dahm**[1]

[1] Deltares, Delft, The Netherlands
[2] Institute for Environmental Studies, VU University Amsterdam, Amsterdam, The Netherlands
[3] Water Footprint Network, Enschede, The Netherlands
[4] Multidisciplinary Water Management group, University of Twente, Enschede, The Netherlands
[5] SIPRI, Stockholm International Peace Research Institute, Stockholm, Sweden
[*] Authors to whom any correspondence should be addressed.

E-mail: henrique.goulart@deltares.nl and h.j.hogeboom@utwente.nl

Keywords: food security, climate-conflict, crop imports, cross-border, drought risk, conflict-affected countries, international trade

Supplementary material for this article is available online

Abstract

Drought events can disrupt food security and increase the risk of violent conflicts. In an interconnected global food system, countries rely on both local food production and imports to meet domestic demand. When assessing the impact of drought risk on national food security, however, imported crops are often overlooked. This study incorporates international crop trade information to understand the role of crop imports in the drought risk profile of countries. We focus on conflict-affected countries due to their reliance on food imports, and particular vulnerability to the impacts of drought events and their corresponding cascading effects. We develop a framework to quantify drought risk associated with domestic production and imports of crops (i.e. composite drought risk) by combining gridded drought risk data with crop production and trade for 23 countries. Our findings show that most conflict-affected countries face drought risk primarily through domestic production, as most consumed calories are produced locally. Nevertheless, including crop imports alters the composite drought risk profiles considerably (>10%) in 13 countries, with changes reaching 40%–50% in some cases. Crop imports also carry their own external drought risk, contributing more than 10% of high drought risk in 21 countries and amounting to 80% in some cases. Furthermore, we identify critical trade connections that expose countries to concentrated drought risks from specific trading partners. We demonstrate the need to incorporate both domestic and import-related drought risks in food security assessments, and we suggest potential strategies based on countries' composite drought risk profiles for drought resilient food security.

1. Introduction

Food security is not only fundamental for human well-being and development, but also for societal stability, with disruptions potentially leading to multiple societal impacts (Jones 2017, Willett *et al* 2019). Food insecurity has been shown to increase social unrest (Bellemare 2015) and undermine health, not only through under nutrition but also via diet-related non-communicable diseases (Martin *et al* 2016, Gundersen and Ziliak 2018, Willett *et al* 2019, Rulli *et al* 2024). Links between food security and violent conflict have been observed across multiple scales, from individual to global levels (Brück and d'Errico 2019, Martin-Shields and Stojetz 2019). Drivers of food insecurity are complex, spanning climatic, socio-economic and political factors (Jagermeyr *et al* 2020, Bowen *et al* 2021, Mottaleb *et al* 2022, Lin *et al* 2023, Wolde *et al* 2023, FSIN 2024). Extreme weather events, such as droughts, can undermine food security by damaging crops, reducing production and cascading to food shortages and price increases (Mach et al 2019, Christian et al 2020, Hasegawa et al 2021, Talebian et al 2024).

Traditional studies on climate-conflict relations focus mainly on climate variables, but the impacts of hydrometeorological variables and extreme weather events like droughts are particularly critical in conflict-affected countries (Dahm et al 2023). This is due to interactions with existing violent conflicts (Von Uexkull et al 2016, Martin-Shields and Stojetz 2019), dependency on rainfed agriculture (Von Uexkull 2014) and limited coping mechanisms (Holleman et al 2017, Jaramillo et al 2023, FSIN 2024). Potential cascading impacts of drought in conflict-affected areas include increased food insecurity, higher number of internal displacements, and more conflicts (Adaawen et al 2019, Anderson et al 2021, Galli et al 2022, Sardo et al 2023).

Drought risk in the context of food security has been primarily assessed for domestic crop production (Vogt et al 2018, Hagenlocher et al 2019, Kogan et al 2019, Hameed et al 2020). This focus often overlooks the drought risks associated with imported crops (Ercin et al 2021), leading to potentially inaccurate estimates of a country's drought risk exposure. Food systems are globally interconnected through international trade, which increases countries' dependencies on food imports, especially in developing countries (Puma et al 2015, Bren D'Amour et al 2016, Kummu et al 2020). While crop trading can mitigate the impacts of local droughts (Dall'Erba et al 2021), disruptions in crop imports, caused by remote droughts, geopolitical conflicts or other events, can hinder food security in importing countries. This is particularly true for the Global South and conflict-affected countries, which are often net food importers (Calì 2014, Burkholz and Schweitzer 2019, Bren D'Amour et al 2020, Talebian et al 2024). For example, studies have linked the 2011 droughts in Russia and Ukraine to a global wheat shortage and price hikes, and subsequently to (at least partially) the occurrence of the Arab Spring (Johnstone and Mazo 2011, Sternberg 2012, Soffiantini 2020).

Under climate change, concurrent droughts and simultaneous crop failures are projected to become more common, increasing risks to the global food system through disruptions in trade connections (Gaupp et al 2019, Qi et al 2022, Goulart et al 2023, Hamed et al 2025). Recent studies found vulnerabilities in the EU's food imports to climate-related risks in exporting countries, and an expected rise in remote drought risk due to climate change (Brás et al 2019, Ercin et al 2021). Therefore, there is growing recognition of the need for countries to assess drought risk both domestically and abroad.

This study quantifies the drought risk for food security in 23 conflict-affected countries, considering both domestic crop production and imports. We develop a framework that quantifies drought risks for agricultural production regions globally and links them to countries' domestic crop production and to their imports. We apply the framework to assess changes in drought risk profiles in countries due to crop imports, to identify critical trade connections between crop-country combinations, and to discuss potential strategies for countries to reduce their composite drought risks.

2. Data and methods

2.1. Conflict-affected countries selection

The data used for conflict-affected countries was obtained from the Georeferenced Event Dataset (GED) version 24.1 from the Uppsala Conflict Data Program (Davies et al 2023). It covers individual events of organized violence at a local scale (such as a village or town) and at a daily temporal scale globally over the 1980–2023 period.

The selection of conflict-affected countries aimed to reflect countries that had chronic issues with violent conflicts in the recent past and that might struggle to cope with the impacts of drought events. We excluded countries classified as high income in the World Banks's classification of countries by income (Ceriani and Verme 2016) and we limited the analysis to the time period between 2000 and 2020 to balance data availability and current day relevance. The selection of conflict-affected countries required calculating conflict years for a given country, which followed two conditions: an absolute threshold requiring a minimum of 100 conflict-related fatalities and a relative threshold of at least 1 conflict-related fatality per 100 000 population (adapted from World Bank 2020). All types of conflicts documented in the GED were considered: state-based conflicts, non-state conflicts and one-sided violence. Conflict-affected countries were defined as countries that presented at least 5 non-consecutive conflict years over the study period. 23 countries were selected as conflict-affected countries (see table 1).

2.2. Framework to connect drought risk to domestic and imported crops

We developed a framework to assess the drought risk of crops consumed in a given country, considering both domestic production and imports, which we refer to as composite drought risk. The framework requires national data on crop production and trade, and gridded data on crop production and drought risk, which are processed and then combined. The specific data and steps are described below.

2.2.1. Crop production and trade

National crop production data were obtained from the crops and livestock products (QCL) database

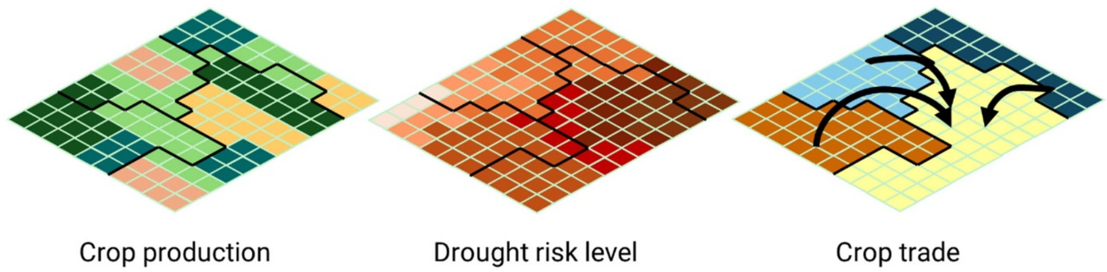

Figure 1. Composite drought risk method description. Colors represent different crop types on left panel, drought risk level on middle panel, and countries on right panel. Black borders indicate country borders and black arrows the direction of crop trade.

(FAO 2024a) and trade data were obtained from the food and agricultural trade matrix (TM) database from the Food and Agriculture Organization of the United Nations (FAO 2024b). The QCL dataset provides yearly crop production data for crops and livestock from 1961 onward, while the TM offers annual data on imports and exports for food and agricultural commodities, covering bilateral trade between countries over the 1986–2022 period. The following staple crops were considered in our analysis: barley, cassava, maize, millet, potatoes, rice, sorghum, soybeans, and wheat. For rice, soybeans, potatoes, and cassava, trade data was adjusted to account for different forms of these crops in trade versus production, with conversions to primary crop equivalents based on FAO conversion factors (FAO 2009), more details on SI section 1. For a uniform comparison of food energy content between different crops, crop data was converted from tons to calories using caloric density values from the FAO. To account for domestic crop production available for national use, we subtracted total exports from the total national production.

We also used a global gridded dataset providing crop production data at a high spatial resolution. This dataset is produced by the global process-based crop model ACEA (Mialyk *et al* 2024) and offers annual simulated production for 175 crops from 1990 to 2019, at a 5-arcminute spatial resolution. It differentiates between rainfed and irrigated production systems. We converted crop production values in each grid cell into relative production values, representing the percentage of local production with respect to the country's national production for a given crop.

2.2.2. Drought risk categories

For assessing drought risk that is relevant to food security, we use a global gridded dataset designed for agricultural systems (Meza *et al* 2020). The dataset provides drought risk information for irrigated and rainfed agricultural systems at a 0.5° spatial resolution and averaged between 1980–2016. Drought risk for each system is based on hazards, exposure, and vulnerability indicators, all normalized and unitless. The agricultural focus supports the connection between drought risk and food security: drought hazards are derived from climate data, exposure from crop information, and vulnerability from agriculture-relevant socioecological indicators. Details on the data are available on Meza *et al* (2020).

We convert drought risk data into categories for easier comparison and interpretation. First, we combined the rainfed and irrigated drought risk data based on their weighted harvest areas to obtain the combined drought risk (also unitless). The data was then downscaled using the nearest neighbor approach to match the spatial resolution of the crop production data. Finally, it was categorized into five discrete classes using a quantile approach, ensuring equal-sized categories, and classified from very low to very high.

2.2.3. Composite drought risk calculation

We combined drought risk and crop production datasets so that each grid cell has information on both the relative production for a given crop and the corresponding drought risk category. We allocated national domestic crop production based on each grid cell's relative domestic production share for the specific crop. Total crop imports from each specific partner were allocated based on the relative production shares within the country of origin's grid cells (figure 1). The composite drought risk of a given country (unitless, due to normalization) was calculated at 5-arcminute resolution by aggregating calorie-weighted domestic crop production and imports across drought risk categories, and then summarizing to the national level. Knowing the origin of drought risk helps understand the contributing factors to the composite drought risk profile of individual countries. They can also support the development of different strategies for both domestic production and international trade to reduce composite drought risk.

2.2.4. Bilateral trade connections

The framework also quantifies the drought risk of individual bilateral trades, which enables the identification of potential external vulnerabilities to a country's food security. We defined critical trade connections as those in which at least 10% of a country's total caloric intake for a specific crop is sourced from high or very high drought risk regions from a single partner country. The 10% threshold is chosen for scalability and realism (Bren D'Amour *et al* 2016). We then determined the number of critical trade connections affecting each conflict-affected country. Identifying critical trade connections can support trade policies aimed at trade diversification.

3. Results

3.1. Domestic crop production and imports in conflict-affected countries

16 out of 23 countries, mainly located in Eastern, Middle, and Western Africa, source most of their calories from domestic production, with most countries importing less than 10% of the domestic production (table 1). However, seven countries import more calories than they produce domestically. They are mainly from the Middle East (6.52 average import/-domestic ratio) and Northern Africa (5.73 ratio), with Lebanon (17.91) and Libya (14.64) showing the highest ratios among all countries analyzed. Latin America (Colombia and Mexico) also imports more than it produces, but at lower ratios (2.10). Southeast Asia shows in general low imports (0.14 ratio), but countries like Pakistan and Sri Lanka import the equivalence of 43% and 44% of their domestic production, respectively. In Southeast Asia, Philippines show an import/domestic ratio of 0.27 while Myanmar does not engage in trade.

3.2. Drought risk in domestic crop production

Coupling domestic crop production with corresponding drought risk levels indicates that 16 countries have at least 30% of their domestic crop production affected by high or very high drought risk (table 2). Furthermore, 11 of these countries have over 50% of their domestic crop production in areas with high or very high drought levels. Yemen (99.7%), Pakistan (97.5%), Iraq (91.9%), Afghanistan (91.8%), Sudan (87.4%), Libya (86.6%), and Sri Lanka (80.9%) face the highest domestic risk, with over three-quarters of their total production in high or very high drought risk level areas. Conversely, countries like Nigeria (2.2%), Central African Republic (CAR) (2.6%), Myanmar (5.9%), Uganda (8.3%) and Cameroon (10.9%) present the lowest drought risk in domestic crop production. Regional analysis indicates the Middle East and North Africa as regions with the highest relative production in high and very high risk (average of 83.7%), while Eastern, Middle, and Western Africa display the lowest contributions from high and very high drought risk in their domestic crop production (17.3% on average).

3.3. Import-related drought risk implications

Beyond analyzing the drought risks in domestic production, we also include imported crops and their corresponding drought risk to quantify the changes in the composite drought risk that countries may face by engaging in international trade (figure 2(a)). 13 out of 23 countries exhibit a shift of at least 10% in their drought risk profile when including crop imports: risk decreases for 8 countries and increases for 5. Countries with large shares of domestic production in high and very high drought risk areas considerably decrease their composite drought risk by importing crops, up to 40%–50% in case of Yemen and Libya. Countries with little domestic crop production in high and very high risk areas experience mild increases in their composite drought risk due to crop imports.

The sources of high and very high drought risk areas are shown in figure 2(b), distinguishing between domestic production and imports. For the majority of conflict-affected countries (15) the main source of high and very high drought risk originates from domestic production. Among the highest-risk countries (Afghanistan, Sudan, Iraq, Pakistan and Sri Lanka), drought risk is dominated by domestic production, making up over 80% of the combined high and very high drought risk levels, and over 50% of the composite drought risk. Nevertheless, import-related drought are still a risk factor as they account in 21 out of 23 countries for at least 10% of their high and very high drought risk. Countries like Lebanon, Libya, Yemen, Syria, Nigeria, Colombia and Algeria have over 50% of their high and very high drought risk from imported crops. Thus, while imports can lower the composite drought risk compared to domestic production alone in many of these countries, a high dependency on crop imports, especially from high and very high drought risk areas, renders their food security vulnerable to droughts beyond their borders. Countries at the bottom of the figure, such as Nigeria and Myanmar, show small blue and yellow bars, indicating small shares of high and very high drought risk from both domestic and imported sources. Further details on the composite drought risk, including results for other drought categories, and for individual crops are available at SI section 3.

3.4. Drought risk profiles of conflict-affected countries

Figure 3 maps each conflict-affected country's domestic drought risk against their import dependency, clustering countries with similar profiles. In cluster 1, Afghanistan, Sudan, Syria, Iraq, Pakistan, and Sri Lanka display high drought risk in domestic production (>80%) and low import dependency (<40%). On the left side of the figure, cluster 2, with Niger, Mali, Nepal and Philippines, indicates moderate drought risk in domestic production (approximately 50%) and low dependency on

Table 1. Crop production and import dependency in conflict-affected countries. Selected countries, domestic crop production (kcal), crop imports (kcal).

Region	Country	Domestic production (billions kcal)	Crop imports (billions kcal)	Import/domestic ratio
Eastern Africa	Burundi	271	58	0.2
	Uganda	1911	239	0.1
Latin America	Colombia	1945	4349	2.2
	Mexico	12 631	24 747	2.0
Middle Africa	Central African Republic	170	2	0.0
	Cameroon	1463	165	0.1
	Democratic Republic of the Congo	3773	194	0.1
Middle East	Iraq	1386	412	0.3
	Lebanon	54	972	17.9
	Syria	1510	2917	1.9
	Yemen	200	1186	5.9
Northern Africa	Algeria	1253	2917	2.3
	Libya	79	1154	14.6
	Sudan	2077	464	0.2
South Asia	Afghanistan	1704	312	0.2
	Nepal	3037	742	0.2
	Pakistan	12 661	5435	0.4
	Sri Lanka	1417	629	0.4
Southeast Asia	Myanmar	11 140	163	0.0
	Philippines	8507	2264	0.3
Western Africa	Mali	2093	89	0.0
	Niger	1522	38	0.0
	Nigeria	16 743	1211	0.1

crop imports (<25%). In cluster 3, CAR, Nigeria, Myanmar, Uganda, and Cameroon, Democratic Republic of the Congo (DR Congo) and Burundi, demonstrate both low drought risk in domestic production and limited import dependency, representing the most drought-resilient profile overall. Countries in cluster 4 (Yemen, Libya, and Algeria) face both high drought risk in domestic production (>60%) and high import dependency (>60%). Colombia and Mexico, cluster 5, reveal drought risk in domestic production between 30% and 50%, and medium import dependency (>40%). Top clusters show a higher risk in domestic production than in crop imports (red dots), while bottom clusters indicate the opposite (blue dots). The robustness of the clusters over different approaches and cases is shown in SI section 2.

3.5. Critical trade connections

A global map combining crop production (in kcal) and drought risk is presented in figure 4(a). Hotspot regions of high crop production and high drought risk are seen in areas of India, China, Russia, North and South America. We identify critical trade connections between crop-country combinations. Their total count provides an estimate of the number of external vulnerabilities to a country's food security. All conflict-affected countries exhibit at least one critical trade connection, with Libya and Lebanon showing the highest numbers (10 connections each), followed by Sudan (9 connections) (figure 4(b)), suggesting broader risk sources to their food security. A small number of suppliers dominate critical trade connections to conflict-affected countries (figure 4(c)). India and Russia each have critical trade connections to 9 countries, followed by the United States (8 countries) and Argentina and Pakistan (7 countries each). These countries correspond closely to the high-production, high-risk regions presented in the global map. Disruptions in these major suppliers could simultaneously affect multiple conflict-affected regions. Among crops, rice emerges as the most critical crop traded globally, accounting for 23 critical trade connections, followed by soybeans (17 connections) and barley (13 connections) (figure 4(d)). We also investigate crop-supplier pairs and find that India has the highest number of critical millet trades (7 connections), Russia of critical wheat trades (7 connections), and Pakistan of critical rice trades (6 connections) (figure SI 6).

Table 2. Percentage of domestic production under different drought risk categories. Drought risk categories range from very low to very high.

Region	Country	Relative domestic production per risk category (%)				
		Very Low	Low	Medium	High	Very High
South Asia	Afghanistan	4	2	2	4	88
South Asia	Pakistan	0	0	2	13	85
Northern Africa	Sudan	0	8	4	5	83
Middle East	Iraq	1	2	5	13	79
South Asia	Sri Lanka	0	10	9	17	64
Northern Africa	Libya	0	1	13	24	63
Middle East	Lebanon	0	19	12	12	57
Middle East	Yemen	0	0	0	47	53
Middle East	Syria	0	2	21	25	52
Northern Africa	Algeria	3	8	15	33	42
Latin America	Mexico	28	14	10	14	35
South Asia	Nepal	12	18	23	15	32
Western Africa	Mali	41	20	6	3	31
Western Africa	Niger	15	23	12	30	20
Southeast Asia	Philippines	6	25	23	26	20
Eastern Africa	Burundi	15	27	43	3	12
Latin America	Colombia	46	15	7	20	11
Middle Africa	Cameroon	68	14	8	2	9
Southeast Asia	Myanmar	43	45	7	3	3
Middle Africa	Central African Republic	97	0	1	1	2
Middle Africa	Democratic Republic of the Congo	32	10	41	15	2
Eastern Africa	Uganda	14	53	25	8	1
Western Africa	Nigeria	70	24	4	2	0

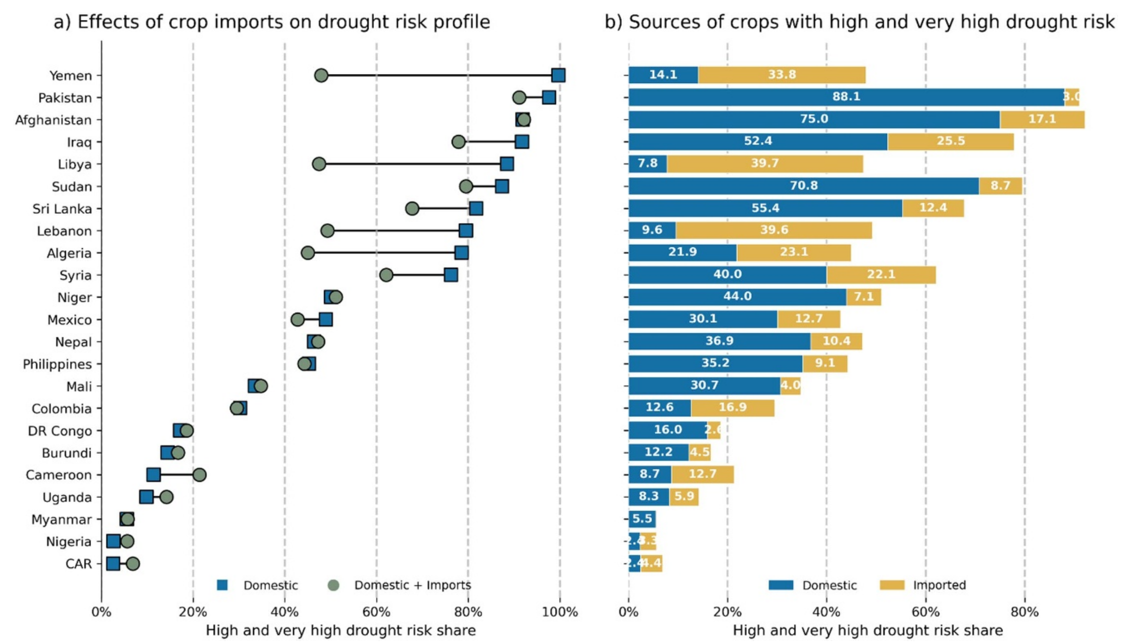

Figure 2. (a) Comparison of drought risk profiles in conflict-affected countries considering domestic production only and including crop imports. Blue squares represent domestic production only, while green circles include imports. (b) Composition of high and very high drought risk by source. Bars represent the percentage of total calories derived from high and very high drought risk areas, subdivided into domestic production (blue) and imports (golden).

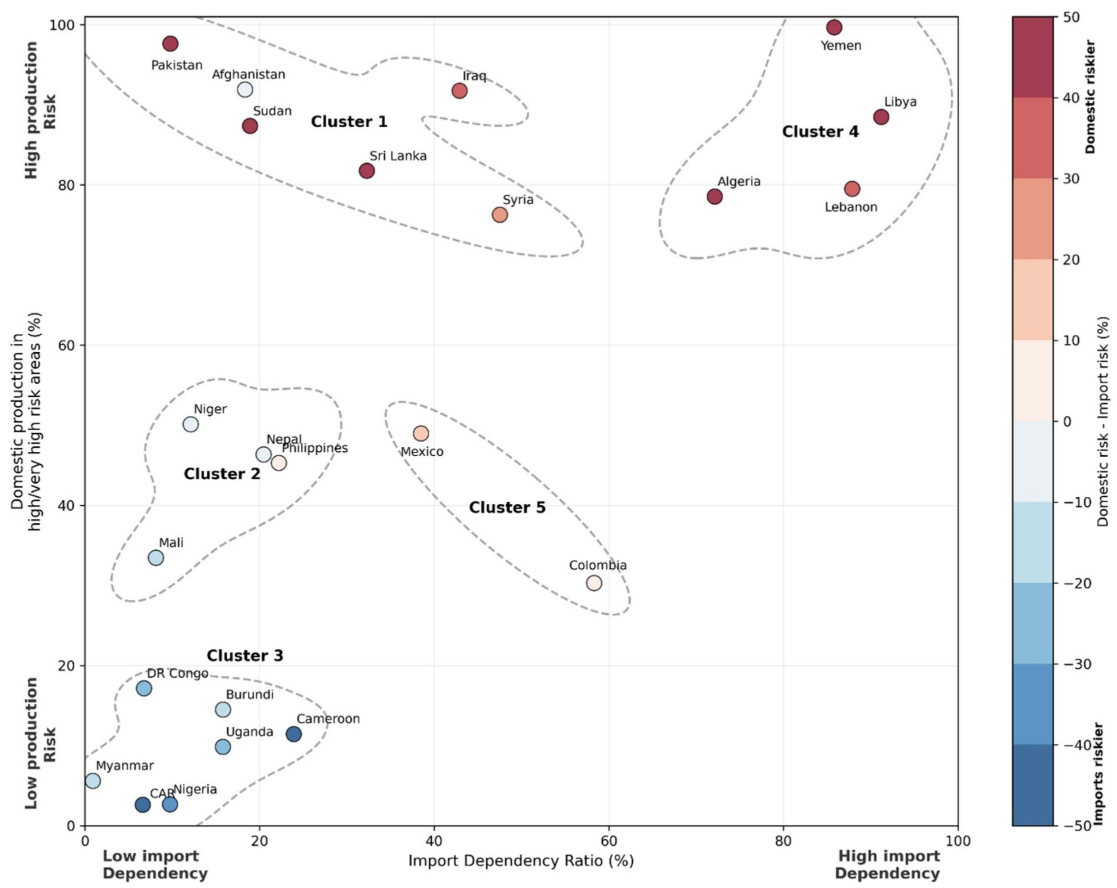

Figure 3. Drought risk profiles of conflict-affected countries across domestic and import-related risk exposure. Colors indicate the risk differential between domestic production and imports (red indicating domestic risk exceeds imported risk and blue vice versa). Dashed contour lines represent clusters of countries with similar risk profiles.

Additionally, the main individual trade connections among crop-country combinations, defined by their critical import magnitude, are shown in Figure SI 7.

The spatial patterns of critical trade connections show distinct vulnerability profiles across countries (figure 5). Libya demonstrates the most geographically dispersed import sources, drawing from multiple global suppliers, while countries like Sudan and Afghanistan show greater reliance on regional partners, creating concentrated geographic vulnerabilities. These patterns indicate that while geographic diversification may reduce some risks, the dominance of few key suppliers creates systemic vulnerabilities that could cascade across multiple regions simultaneously.

4. Discussion

Drought events can exacerbate both food insecurity and conflicts, which are on their own mutually reinforcing (Tschunkert and Delgado 2022, Jaramillo *et al* 2023, Sova *et al* 2023). In an interconnected global food system, many countries depend on food imports, potentially mitigating domestic drought vulnerability but making them vulnerable to droughts outside of their borders. This study incorporates international crop trade information into drought risk assessment to understand the role of crop imports in the drought risk profile of conflict-affected countries, and to identify critical trade connections that may amplify food insecurity.

4.1. Crop imports matter for drought risk assessment

Domestic production is the primary driver of drought risk to crop consumption in most conflict-affected countries, largely because the majority of their calories are sourced domestically. However, crop imports are still relevant for many countries as they shift composite drought risk considerably: in 13 of 23 countries, crop imports change high and very high drought risk levels by at least 10%, with changes reaching up to 50% in extreme cases. Crop imports also introduce drought risk from trading partners, accounting for at least 10% of high drought risk in 21 countries, and reaching approximately 80% in cases like Lebanon and Libya. Other studies documented approximate results by analyzing vulnerabilities to remote disruptions and shocks in similar regions (Bren D'Amour *et al* 2016, Burkholz and Schweitzer 2019).

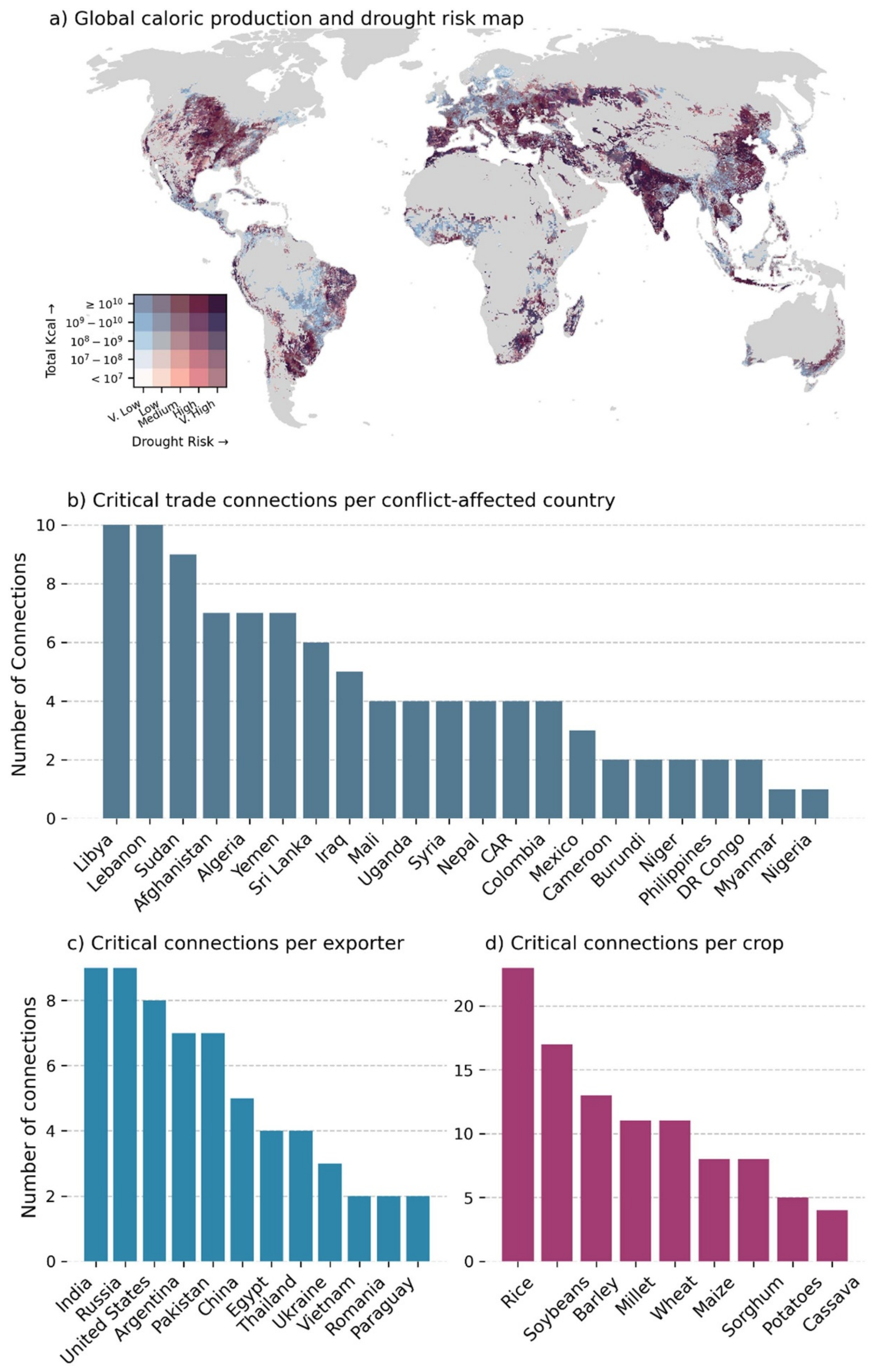

Figure 4. (a) Bivariate map combining crop production and drought risk. (b) Number of critical trade connections among conflict-affected countries. (c) Bar indicating exporting countries with the highest number of critical trade connections to conflict-affected countries. (d) Number of critical trade connections per crop type.

Recent studies found that climate-related hazards in exporting regions, like droughts, matters when assessing importing countries' food security (Brás *et al* 2019, Ercin *et al* 2021). Our results reinforce these findings by showing that the inclusion of crop imports alters drought risk profiles in many conflict-affected countries. Since food security forms an important mediating variable in climate-conflict pathways, we argue that studies focusing solely on domestic drought risk can present an incomplete

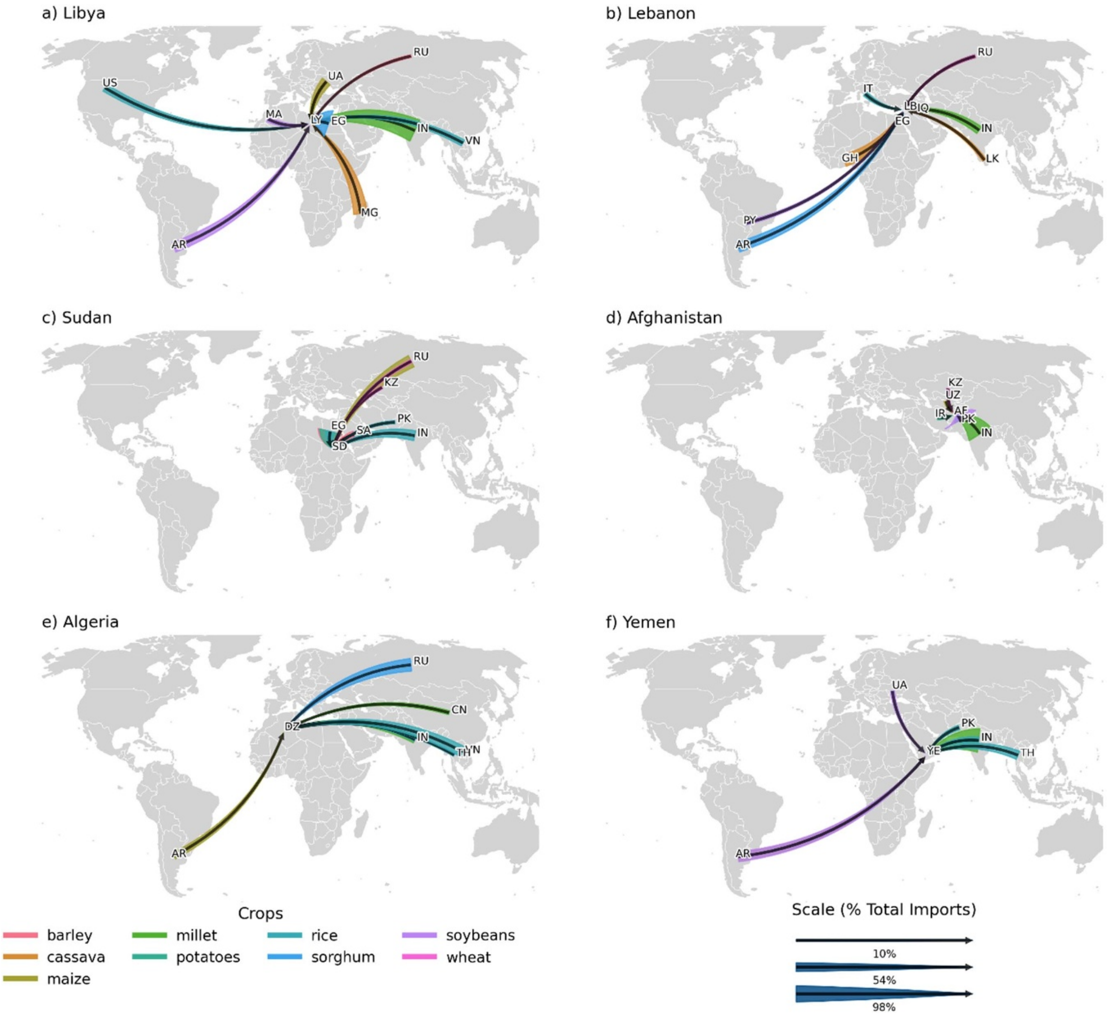

Figure 5. Visual demonstration of the critical trade connections for conflict-affected countries with the highest number of critical trade connections. Colors indicate the type of crop, and the width of the connecting arrows represent the magnitude of the trade connection (%). Acronyms indicate each country's name.

picture of the dynamics between climate, food security and violent conflict.

4.2. Potential strategies based on composite drought risk profiles

The findings of this study have policy making implications and can be used to support tailored strategies to countries in different circumstances. Countries that have high domestic production risk but have low import dependency (e.g. Afghanistan and Sudan from cluster 1 in figure 4) can improve domestic crop production e.g. through improved water management, or shifting to more drought-resistant and sustainable crop varieties and types (Mustafa *et al* 2019, Ricciardi *et al* 2024, Talebian *et al* 2024). Such countries can also explore opportunities to increase crop imports from low drought risk regions or pursue internal cooperation (Kuhla *et al* 2024), such as regional trade agreements with grain reserves (Kornher and Kalkuhl 2016). Countries with both high domestic risk and high import dependency (e.g. Yemen, Libya, cluster 4) can combine efforts to reduce domestic vulnerability with actions to diversify imports. Some of these countries face arid desert conditions that limit domestic agriculture expansion (Bren D'Amour *et al* 2016), and focus should be in diversifying towards trade partners in low-drought risk areas (Aguiar *et al* 2020). Critical trade connection can help identify the riskiest import partners. Countries with low domestic drought risk but high import dependence (cluster 5) can expand their low drought risk crop production areas, or diversify imports to lower risk areas. Countries with the lowest composite drought risk and low import dependency (cluster 3) can maintain their current approach to domestic crop production, while monitoring for potential changes in demand or climate conditions. This latter group of countries, however, may play a mitigating role in reducing drought risk exposure in other countries: if they expand their sustainable domestic production and export additional production under low drought risk, they may pre-empt the need to produce those crops in high drought risk countries that import from them (Hogeboom 2020).

Such expansion should avoid undermining water sustainability (*in situ* or downstream) and prioritize nutrient-dense local consumption to ensure broader food and nutritional security (Galli *et al* 2023, Mehta *et al* 2025). A readily available strategy for all countries is to identify their main drought risk vulnerabilities domestically and remotely. Mapping vulnerabilities and critical trade connections helps to better direct resources towards monitoring and anticipating drought conditions in key domestic or external areas (Funk *et al* 2019, Busker *et al* 2023).

4.3. Limitations and future research

Our study focused solely on the drought aspect of food security. However, food security is a complex topic with multiple drivers and interactions, including other climate hazards, conflicts, displacement and economic drivers (FSIN 2024). Some of the strategies in this study suggest crop imports to reduce the composite drought risk, but international food trade also carries geopolitical implications. Recent disruptions from the Russia–Ukraine war illustrate how conflicts can trigger supply shocks and global price hikes, with disproportionate impacts on import-dependent countries (Carriquiry *et al* 2022, Bertassello *et al* 2023, Jia *et al* 2024). These dynamics can further cascade into structural changes in global land and resource use (Dell'Angelo *et al* 2023). While the drought risk data accounts for crop-specific water requirements in its calculations (Meza *et al* 2020), the final risk values are aggregated across all crops within each grid cell, which may not fully capture the specific drought vulnerabilities of individual crop types (Dietz *et al* 2021). International food trade is both complex and data sensitive. While the most comprehensive public database for food trade, the FAO TM does not have data for all countries and trade flows, possibly due to countries not disclosing their trade partnerships, limiting the number of countries included in the analysis. The data is also not suited for accounting for re-exports (exports of imported products), which has been considered in other studies (Ali *et al* 2021). Additionally, drought risk, crop production and crop trade data are averages of past time periods, which may not reflect future conditions under climate change. Our analysis does not account for indirect effects such as the role of intermediate countries in trade and food processing, which exclude other potential trade chain disruptions (Burkholz and Schweitzer 2019).

Besides including import-related drought risk, future research could also account for changes in future drought risk (Qi *et al* 2022), crop production and consumption (Lehtonen *et al* 2021), and trade policies (Wu *et al* 2024). Storyline approaches can explore these scenarios through specific event sequences and quantifying cascading effects (Goulart *et al* 2021, van den Hurk *et al* 2023). Studies could also consider water footprint to include virtual water trading, which accounts for intermediaries between crop producing and consuming regions (Hogeboom 2020). Additionally, future studies could explore interannual variability of droughts and crop trades, or investigate the potential uses and benefits of early warning systems (such as seasonal weather forecasts) combined with our method. While calorie availability is central to food security assessments, it does not capture the adequacy of diets in terms of micronutrients (Ricciardi *et al* 2024). Future research could extend our framework to micronutrient intake and to a more extensive supply chain coverage (e.g. processed crops), allowing for more comprehensive assessments of drought risk impacts on health and nutrition.

5. Conclusions

This study investigates drought risk to crop consumption in 23 conflict-affected countries, considering both domestic production and imports. While domestic production accounts for the majority of composite drought risk, crop imports both alter the drought risk profiles in most countries and add considerable sources of high drought risk from remote areas. Food security assessment studies should therefore incorporate both domestic and remote drought risks, particularly in the climate-conflict research area. We propose a method to identify critical trade connections between country-crop combinations to support targeted actions, and suggest ways to use this information in strategies to reduce the risk of droughts and improve food security in conflict-affected countries.

Data availability statement

The drought risk dataset is available at Meza *et al* (2020). Crop yield data is available at Mialyk *et al* (2024).

The data and code that support the findings of this study are openly available at the following URL/DOI: https://github.com/dumontgoulart/crop_imports_drought_risk (Goulart 2025).

Supplementary information available at https://doi.org/10.1088/1748-9326/ae1bbf/data1.

Acknowledgments

HG and RD received funding by the SITO Institute Subsidy programme, supported by the Dutch Ministry of Economic Affairs. RJH received funding from the Dutch Research Council (NWO), with Grant Number VI.Veni.221S.080.

Author contributions

Henrique M D Goulart 0000-0002-9670-4250
Conceptualization (equal), Data curation (lead), Formal analysis (lead), Investigation (lead), Methodology (lead), Project administration (equal), Validation (lead), Visualization (lead), Writing – original draft (lead), Writing – review & editing (lead)

Raed Hamed 0000-0003-2243-3109
Data curation (supporting), Formal analysis (supporting), Methodology (supporting), Writing – review & editing (supporting)

Rick J Hogeboom
Conceptualization (supporting), Data curation (supporting), Methodology (supporting), Resources (supporting), Supervision (supporting), Writing – review & editing (supporting)

Karen Meijer
Conceptualization (supporting), Methodology (supporting), Writing – review & editing (supporting)

Ruben Dahm 0000-0002-8667-3358
Conceptualization (equal), Funding acquisition (lead), Methodology (supporting), Project administration (equal), Resources (supporting), Supervision (lead), Writing – review & editing (supporting)

References

Adaawen S, Rademacher-Schulz C, Schraven B and Segadlo N 2019 *Drought, Migration, and Conflict in sub-Saharan Africa: What are the Links and Policy Options?* vol 2 (Elsevier) pp 15–31

Aguiar S, Texeira M, Garibaldi L A and Jobbágy E G 2020 Global changes in crop diversity: trade rather than production enriches supply *Glob. Food Secur.* **26** 100385

Ali T, Xie W, Zhu A and Davis K F 2021 Accounting for re-exports substantially reduces China's virtual water demand through agricultural trade *Environ. Res. Lett.* **16** 045002

Anderson W, Taylor C, McDermid S, Ilboudo-Nébié E, Seager R, Schlenker W, Cottier F, de Sherbinin A, Mendeloff D and Markey K 2021 Violent conflict exacerbated drought-related food insecurity between 2009 and 2019 in sub-Saharan Africa *Nat. Food* **2** 603–15

Bellemare M F 2015 Rising food prices, food price volatility, and social unrest *Am. J. Agric. Environ.* **97** 1–21

Bertassello L, Winters P and Müller M F 2023 Access to global wheat reserves determines country-level vulnerability to conflict-induced Ukrainian wheat supply disruption *Nat. Food* **4** 673–6

Bowen S, Elliott S and Hardison-Moody A 2021 The structural roots of food insecurity: how racism is a fundamental cause of food insecurity *Sociol. Compass* **15** e12846

Brás T A, Jägermeyr J and Seixas J 2019 Exposure of the EU-28 food imports to extreme weather disasters in exporting countries *Food Secur.* **11** 1373–93

Bren D'Amour C, Bren D'Amour C, Bren D'Amour C and Anderson W 2020 International trade and the stability of food supplies in the Global South *Environ. Res. Lett.* **15** 074005

Bren D'Amour C, Wenz L, Kalkuhl M, Christoph Steckel J and Creutzig F 2016 Teleconnected food supply shocks *Environ. Res. Lett.* **11** 035007

Brück T and d'Errico M 2019 Reprint of: food security and violent conflict: introduction to the special issue *World Dev.* **119** 145–9

Burkholz R and Schweitzer F 2019 International crop trade networks: the impact of shocks and cascades *Environ. Res. Lett.* **14** 114013

Busker T, de Moel H, van den Hurk B and Aerts J C J H 2023 Impact-based seasonal rainfall forecasting to trigger early action for droughts *Sci. Total Environ.* **898** 165506

Calì M 2014 Trading away from conflict: using trade to increase resilience in fragile states *Trading Away from Conflict: Using Trade to Increase Resilience in Fragile States* (World Bank) (https://doi.org/10.1596/978-1-4648-0308-6)

Carriquiry M, Dumortier J and Elobeid A 2022 Trade scenarios compensating for halted wheat and maize exports from Russia and Ukraine increase carbon emissions without easing food insecurity *Nat. Food* **3** 847–50

Ceriani L and Verme P 2016 The World Bank's classification of countries by income *J. Dev. Stud.* **50** 1510–22

Christian J I, Basara J B, Hunt E D, Otkin J A and Xiao X 2020 Flash drought development and cascading impacts associated with the 2010 Russian heatwave *Environ. Res. Lett.* **15** 094078

Dahm R, Meijer K, Kuneman E and van Schaik L 2023 What climate? The different meaning of climate indicators in violent conflict studies *Clim. Change* **176** 1–23

Dall'Erba S, Chen Z and Nava N J 2021 U.S. interstate trade will mitigate the negative impact of climate change on crop profit *Am. J. Agric. Environ.* **103** 1720–41

Davies S, Pettersson T and Öberg M 2023 Organized violence 1989–2022, and the return of conflict between states *J. Peace Res.* **60** 691–708

Dell'Angelo J, Rulli M C and D'Odorico P 2023 Will war in Ukraine escalate the global land rush? *Science* **379** 752–5

Dietz K-J, Zörb C and Geilfus C-M 2021 Drought and crop yield *Plant Biol.* **23** 881–93

Ercin E, Veldkamp T I E and Hunink J 2021 Cross-border climate vulnerabilities of the European Union to drought *Nat. Commun.* **12** 1–10

FAO 2009 Technical conversion factors for agricultural commodities (available at: www.fao.org/fileadmin/templates/ess/documents/methodology/tcf.pdf)

FAO 2024a *FAOSTAT: crops and livestock products (QCL)*

FAO 2024b FAOSTAT: detailed trade matrix (TM) (FAO) (available at: www.fao.org/faostat/en/#data/TM)

FSIN 2024 Global report on food crises (GRFC) 2024 (available at: www.fsinplatform.org/report/global-report-food-crises-2024)

Funk C *et al* 2019 Recognizing the famine early warning systems network: over 30 years of drought early warning science advances and partnerships promoting global food security *Bull. Am. Meteorol. Soc.* **100** 1011–27

Galli N, Chiarelli D D, Ricciardi L and Rulli M C 2023 A blue water scarcity-based method for hydrologically sustainable agricultural expansion design *Water Resour. Res.* **59** e2023WR034473

Galli N, Dell'Angelo J, Epifani I, Chiarelli D D and Rulli M C 2022 Socio-hydrological features of armed conflicts in the Lake Chad Basin *Nat. Sustain.* **5** 843–52

Gaupp F, Hall J, Hochrainer-Stigler S and Dadson S 2019 Changing risks of simultaneous global breadbasket failure *Nat. Clim. Change* **10** 54–57

Goulart H M D 2025 Repository for scripts and data for food security beyond borders: how crop imports affect drought risk of conflict-affected countries *GitHub* (available at:

https://github.com/dumontgoulart/crop_imports_drought_risk)
Goulart H M D, Van Der Wiel K, Folberth C, Balkovic J and Van Den Hurk B 2021 Storylines of weather-induced crop failure events under climate change *Earth Syst. Dyn.* **12** 1503–27
Goulart H M D, van der Wiel K, Folberth C, Boere E and van den Hurk B 2023 Increase of simultaneous soybean failures due to climate change *Earth's Future* **11** e2022EF003106
Gundersen C and Ziliak J P 2018 Food insecurity research in the United States: where we have been and where we need to go *Appl. Econ. Perspect. Policy* **40** 119–35
Hagenlocher M, Meza I, Anderson C C, Min A, Renaud F G, Walz Y, Siebert S and Sebesvari Z 2019 Drought vulnerability and risk assessments: state of the art, persistent gaps, and research agenda *Environ. Res. Lett.* **14** 083002
Hamed R, Lesk C, Shepherd T G, Goulart H M D, van Garderen L, van den Hurk B and Coumou D 2025 One-third of the global soybean production failure in 2012 is attributable to climate change *Commun. Earth Environ.* **6** 1–9
Hameed M, Ahmadalipour A and Moradkhani H 2020 Drought and food security in the Middle East: an analytical framework *Agric. For. Meteorol.* **281** 107816
Hasegawa T, Sakurai G, Fujimori S, Takahashi K, Hijioka Y and Masui T 2021 Extreme climate events increase risk of global food insecurity and adaptation needs *Nat. Food* **2** 587–95
Hogeboom R J 2020 The water footprint concept and water's grand environmental challenges *One Earth* **2** 218–22
Holleman C, Jackson J, Sánchez M V and Vos R 2017 Sowing the seeds of peace for food security. Disentangling the nexus between conflict, food security and peace (available at: https://ageconsearch.umn.edu/record/296657)
Jagermeyr J *et al* 2020 A regional nuclear conflict would compromise global food security *Proc. Natl Acad. Sci. USA* **117** 7071–81
Jaramillo L, Cebotari A, Diallo Y, Gupta R and Koshima Y 2023 Climate challenges in fragile and conflict-affected states (available at: https://books.google.com/books?hl=en&lr=&id=j2_VEAAAQBAJ&oi=fnd&pg=PP1&dq=Climate+Challenges+in+Fragile+and+Conflict-Affected+States+By+Laura+Jaramill&ots=Q0oNR7E9ZN&sig=qV6NwBwT2BE0mrM2lkzjT9aSbSs)
Jia N, Xia Z, Li Y, Yu X, Wu X, Li Y, Su R, Wang M, Chen R and Liu J 2024 The Russia-Ukraine war reduced food production and exports with a disparate geographical impact worldwide check for updates *Commun. Earth Environ.* **5** 765
Johnstone S and Mazo J 2011 Global warming and the Arab spring *Survival* **53** 11–17
Jones A D 2017 Food insecurity and mental health status: a global analysis of 149 countries *Am. J. Prev. Med.* **53** 264–73
Kogan F, Guo W and Yang W 2019 Drought and food security prediction from NOAA new generation of operational satellites *Geomat. Nat. Hazards Risk* **10** 651–66
Kornher L and Kalkuhl M 2016 The costs and benefits of regional cooperation on grain reserves: the case of ECOWAS *Food Price Volatility and Its Implications for Food Security and Policy* (Springer) pp 353–84
Kuhla K, Puma M J and Otto C 2024 International cooperation was key to stabilize wheat prices after the Russian Invasion of Ukraine *Commun. Earth Environ.* **5** 1–15
Kummu M, Kinnunen P, Lehikoinen E, Porkka M, Queiroz C, Röös E, Troell M and Weil C 2020 Interplay of trade and food system resilience: gains on supply diversity over time at the cost of trade independency *Glob. Food Secur.* **24** 100360
Lehtonen H S *et al* 2021 Shared socioeconomic pathways for climate change research in Finland: co-developing extended SSP narratives for agriculture *Reg. Environ. Change* **21** 1–16
Lin F, Li X, Jia N, Feng F, Huang H, Huang J, Fan S, Ciais P and Song X-P 2023 The impact of Russia-Ukraine conflict on global food security *Glob. Food Secur.* **36** 100661
Mach K J *et al* 2019 Climate as a risk factor for armed conflict *Nature* **571** 193–7
Martin M S, Maddocks E, Chen Y, Gilman S E and Colman I 2016 Food insecurity and mental illness: disproportionate impacts in the context of perceived stress and social isolation *Public Health* **132** 86–91
Martin-Shields C P and Stojetz W 2019 Food security and conflict: empirical challenges and future opportunities for research and policy making on food security and conflict *World Dev.* **119** 150–64
Mehta P, Muller M, Niles M T and Davis K F 2025 Child diet diversity and irrigation expansion in the global south *Nat. Sustain.* **8** 905–13
Meza I *et al* 2020 Global-scale drought risk assessment for agricultural systems *Nat. Hazards Earth Syst. Sci.* **20** 695–712
Mialyk O, Schyns J F, Booij M J, Su H, Hogeboom R J and Berger M 2024 Water footprints and crop water use of 175 individual crops for 1990–2019 simulated with a global crop model *Sci. Data* **11** 1–16
Mottaleb K A, Kruseman G and Snapp S 2022 Potential impacts of Ukraine-Russia armed conflict on global wheat food security: a quantitative exploration *Glob. Food Secur.* **35** 100659
Mustafa M A, Mayes S and Massawe F 2019 Crop diversification through a wider use of underutilised crops: a strategy to ensure food and nutrition security in the face of climate change *Sustainable Solutions for Food Security: Combating Climate Change by Adaptation* (Springer) pp 125–49
Puma M J, Bose S, Chon S Y and Cook B I 2015 Assessing the evolving fragility of the global food system *Environ. Res. Lett.* **10** 024007
Qi W, Feng L, Yang H and Liu J 2022 Increasing concurrent drought probability in global main crop production countries *Geophys. Res. Lett.* **49** e2021GL097060
Ricciardi L, D'Odorico P, Chiarelli D D and Rulli M C 2024 To what extent can agriculture be reshaped to address healthy and sustainable diets by boosting pulse production locally? *Glob. Food Secur.* **40** 100734
Rulli M C, Sardo M, Ricciardi L, Govoni C, Galli N, Chiarelli D D, Komarek A M and D'Odorico P 2024 Meeting the EAT-Lancet 'healthy' diet target while protecting land and water resources *Nat. Sustain.* **7** 1651–61
Sardo M, Epifani I, D'Odorico P, Galli N and Rulli M C 2023 Exploring the water–food nexus reveals the interlinkages with urban human conflicts in Central America *Nat. Water* **1** 348–58
Soffiantini G 2020 Food insecurity and political instability during the Arab Spring *Glob. Food Secur.* **26** 100400
Sova C, Fountain G, Zembilci E and Carr T 2023 Dangerously hungry: the link between food insecurity and conflict
Sternberg T 2012 Chinese drought, bread and the Arab Spring *Appl. Geogr.* **34** 519–24
Talebian S, Lager F, Harris K and Cole M 2024 *Solutions for Managing Food Security Risks in a Rapidly Changing Geopolitical Landscape* (Stockholm Environment Institute) (https://doi.org/10.51414/SEI2024.044)
Tschunkert K and Delgado C 2022 Food systems in conflict and peacebuilding settings: ways forward (https://doi.org/10.55163/SSKG9519)
van den Hurk B *et al* 2023 Climate impact storylines for assessing socio-economic responses to remote events *Clim. Risk Manage.* **40** 100500
Vogt J V, Naumann G, Masante D, Spinoni J, Cammalleri C, Erian W, Pischke F, Pulwarty R and Barbosa P 2018 Drought risk assessment. A conceptual framework (*publications.jrc.ec.europa.eu*) (https://doi.org/10.2760/057223)
Von Uexkull N 2014 Sustained drought, vulnerability and civil conflict in Sub-Saharan Africa *Political Geogr.* **43** 16–26

Von Uexkull N, Croicu M, Fjelde H and Buhaug H 2016 Civil conflict sensitivity to growing-season drought *Proc. Natl Acad. Sci. USA* **113** 12391–6

Willett W *et al* 2019 Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems *Lancet* **393** 447–92

Wolde S G, D'Odorico P and Rulli M C 2023 Environmental drivers of human migration in Sub-Saharan Africa *Glob. Sustain.* **6** e9

World Bank 2020 World Bank group strategy for fragility, conflict, and violence 2020–2025 (available at: https://documents.worldbank.org/en/publication/documents-reports/documentdetail/844591582815510521/world-bank-group-strategy-for-fragility-conflict-and-violence-2020-2025)

Wu D, Chen J, Xiong L, Lee J-H, Kim J-S and Moon H-T 2024 Assessing global drought conditions under climate change: a comparison of stationary and non-stationary approaches and identification of hotspot regions *J. Hydrol.* **640** 131663