Assessing food security disruptions in the aftermath of extreme events

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Abstract

Climate change can potentially drive variations in the frequency and magnitude of hydrological extremes, and in turn the impact these events have on agriculture. Agricultural damages resulting from extreme events can significantly affect food security at multiple scales, especially in contexts where pre-existing unfavourable social and economic conditions already hinder the stability and the effectivity of the food supply chain. In these contexts, formulating approaches to directly quantify food security impacts of extreme events in a way that is compatible with local data availability, but at the same time reliable and transparent, becomes a crucial and urgent matter. Moreover, while the importance of the multifaceted repercussions of agricultural damage on food security have been highlighted in the current literature, investigation on impacts different than reduced crop availability remain understudied. Here, we propose a methodology to derive metrics of food availability and food access impacts from post-disaster assessments, by putting the affected communities at the core of the analysis. We then provide perspectives on food utilization and food stability impacts. We apply the methodology on the severe floods that affected Malawi in the early months of 2015. We find that agricultural losses correspond to food sufficient for feeding more than 300,000 people and for balancing the diet of almost 2.3 million. Food security impacts also appear to disproportionately hit poorer and less food-secure districts. The proposed methodology is easily replicable in other case studies, also moving beyond floods as the triggering extreme event.

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Abstract

Climate change can potentially drive variations in the frequency and magnitude of hydrological extremes, and in turn the impact these events have on agriculture. Agricultural damages resulting from extreme events can significantly affect food security at multiple scales, especially in contexts where pre-existing unfavourable social and economic conditions already hinder the stability and the effectivity of the food supply chain. In these contexts, formulating approaches to directly quantify food security impacts of extreme events in a way that is compatible with local data availability, but at the same time reliable and transparent, becomes a crucial and urgent matter. Moreover, while the importance of the multifaceted repercussions of agricultural damage on food security have been highlighted in the current literature, investigation on impacts different than reduced crop availability remain understudied. Here, we propose a methodology to derive metrics of food availability and food access impacts from post-disaster assessments, by putting the affected communities at the core of the analysis. We then provide perspectives on food utilization and food stability impacts. We apply the methodology on the severe floods that affected Malawi in the early months of 2015. We find that agricultural losses correspond to food sufficient for feeding more than 300,000 people and for balancing the diet of almost 2.3 million. Food security impacts also appear to disproportionately hit poorer and less food-secure districts. The proposed methodology is easily replicable in other case studies, also moving beyond floods as the triggering extreme event.

Keywords: hydrological extremes, food security, land and water resources, food system resilience.

1. Introduction

Climate change has altered rainfall patterns across the globe, in a way that in some cases has increased the frequency and magnitude of hydrological extremes, such as droughts and floods (Alexander et al., 2012). Such hydrological extremes, as well as other effect of climate change, typically tend to affect disproportionately communities and regions of the world that are socially and economically disadvantaged (Islam & Winkel, 2017). Indeed, developing countries in tropical and subtropical regions, already often challenged in their ability to sustain the livelihoods of their populations, are those where the impacts of climate change on ecosystems and human systems are expected to be the strongest (Thornton et al., 2014). Still in this context, disruptions arising from extreme events often hit on, and combine with, a context of pre-existing institutional weakness and reduced economic capacity (Adger et al., 2014; Vivekananda et al., 2014). This can potentially produce interactions of the impacts of these extreme events with other types of environmental and social stressors (Gaupp, 2020). Indeed, the same pre-existing conditions that generate chronic socio-economic and environmental stress are likely to be those increasing vulnerability, and decreasing the coping capacity, of these contexts to acute shocks such as extreme events (Buhaug & Von Uexkull, 2021). As a consequence, understanding the multifaceted impacts of climate change on extreme events, and in turn, on environmental and human systems in developing regions of the world is an important and urgent research matter, as risks associated with this type of disruptions are likely to go well beyond those typically assessed (Lesk et al., 2016). In particular, agricultural damages of hydrological extremes can be considered a relevant embodiment of water-food interactions in the water-energy-food nexus (Pacetti et al., 2017; Zhang et al., 2018). Water is essential for agricultural production, in such a way that both a deficit and an excess of it can cause agricultural disruptions that propagate along the food supply chain. Droughts reduce crop yields through water stress, ultimately leading to crop failure, while floods destroy crop fields nullifying the potential yield. In both cases, not only the agricultural production is lost, but also water resources used to sustain until the event are wasted, and land resources are unusable until recovery (Pacetti et al., 2017). This loss in agricultural production can have widespread and diversified impacts on food security. Previous studies have highlighted these multifaceted impacts while assessing effects of climate change on extreme events (Abiodun et al., 2013), or agricultural damage caused by hydrological extremes (Prima Ari Pratiwi et al., 2020). In some cases food availability effects have been directly quantified in terms of lost calories associated to agricultural disruption (Pacetti et al., 2017). Yet, this agricultural disruption can translate into food security impacts in more ways, depending on the path the specific lost agricultural item follows on the supply chain. In the case of agricultural goods produced for domestic consumption, losses translate quite straightforwardly into decreases in food availability. In the case of agricultural products with non-food destinations, or agricultural goods destined to export, the pathway leading from agricultural damage to food insecurity can be longer and more complex, even though no less important. The definition of food security, the condition *when people, at all times, have physical and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life* (Shaw, 2007), is typically articulated into four pillars: availability, access, utilization and stability (FAO & European Union, 2008). Clearly, food-security effects of agricultural disruptions from extreme events have a mutual exacerbation relationship to food stability. Countries with higher food stability have, in theory, higher coping capacity with respect to food supply shocks generated by extreme events, and food stability is, among the four pillars, the most directly impacted by extreme events, overarching, in a way, impacts on other pillars. Disruption of agricultural goods produced for their economic value rather than their nutrition value (e.g., cash crops) is clearly a matter of food access rather than food availability. Finally, health risks associated to unsafe foods and altered nutrient intake as a result of reduced food availability can be seen as food utilization impacts of agricultural damage due to extreme events. All these diversified impacts of hydrological extremes on food security are exacerbated in contexts where high dependence on agriculture and low reaction capacity increase both exposure and vulnerability of the agricultural sector. Clearly, food availability impacts are stronger where smallholder farming for direct consumption occupies a more relevant role. Food access impacts are enhanced by vulnerable trade networks that are unable to absorb food supply shocks. Food utilization impacts can be expected to be sensitive to the pre-existing state of health and sanitation infrastructures. As marginalized contexts are also more vulnerable to extreme events, these same vulnerable contexts are also the environments where agricultural disruptions caused by extreme events are most likely to have tangible impacts on food security. Moreover, food security impacts are more likely to have a relevant social dimension where pre-existing conditions are less favourable. To this adds the low availability, in marginalized regions, of data to support sophisticated, data-intensive, damage assessment methodologies. Therefore, there is the need for an approach able to explicitly evaluate food security impacts of extreme events from a multi-pillar perspective, basing on assessments that are typically performed on the field in the aftermath of calamities in developing countries instead of relying fully on models that could be characterized by high uncertainty. Also, such an approach should put the impacted communities at the core of the analysis, so that different dimensions of food security are assessed in the form in which they effectively are impacted by hydrological extremes and, in turn, impact on people's livelihoods. Here we propose a methodology that leverages information on agricultural losses obtained during the emergency and has been consolidated and validated on the field. We derive pillar-specific quantifications of food security impacts in terms of impacted people equivalents at the subnational scale and interpret and discuss the results considering national, subnational and disaggregated data on pre-existing socio-environmental and economic conditions. We perform the analysis for the case of the 2015 floods in Malawi, the most severe on record for the country, which have affected more than one million people, displaced 230,000 and killed more than one hundred, and produced an estimated recovery and reconstruction cost of 494 million US$ (GFDRR et al., 2015).

2. Materials and methods

Malawi is a country located in South-eastern Africa, extending over 118,480 km^2 between Tanzania, Mozambique and Zambia (AQUASTAT, 2006). As of 2015, the population of Malawi reached 16.94 million people, while current population is 19.89 million people (The World Bank Group, 2022). Of the country's population, 85% lives in rural areas (GFDRR et al., 2016). Agriculture the most relevant sector in Malawi's economy (Stevens & Madani, 2016), accounting for 27.5% of the country's GDP in 2015 (The World Bank Group, 2022). The most harvested crops are maize, pulses, groundnuts, potatoes and sweet potatoes, and cassava, while rice, despite occupying a minor share of harvested areas, is the main irrigated crop in the Southern part of the country (Frolking et al., 2020). Most of the cereals and tubers are planted during the first half of the rainy season, namely between November and December, while cotton, sugarcane and tobacco are planted in January, February and June, respectively, and vegetables are grown throughout the year (Chapagain & Hoekstra, 2004; FAO, 2023). The climate of Malawi is tropical continental, as Malawi is a landlocked country, so the water mass mostly influencing the climate is lake Malawi (AQUASTAT, 2006). However, tropical cyclone cells originating in the Indian Ocean can reach Malawi, generating intense rainfall with associated flood risk (AQUASTAT, 2006). These extreme rainfalls have been increasing in frequency as a consequence of climate change, especially in the Lower Shire, the Southern part of the country which is also a major agricultural hub (GFDRR et al., 2015). In particular, rainfall occurred in January 2015 in the southern districts was characterized by a 500-year return period, constituting the highest rainfall on record for the country and producing the most severe floods for the country in recent history (GFDRR et al., 2015; The World Bank Group & GFDRR, 2019). The floods produced extensive impacts on agriculture and livestock systems, as well as transport and sanitation infrastructures (GFDRR et al., 2015).

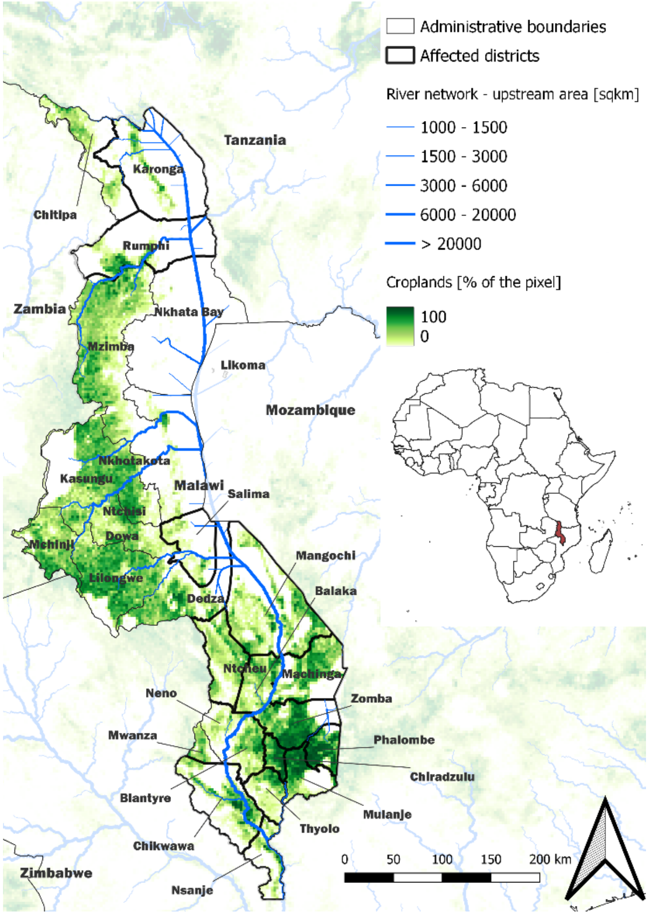

Figure 1. Map of the study area. The river network is taken from (Lehner & Grill, 2013)*, the cropland maps are taken from* (Potapov et al., 2021)*.*

The Post Disaster Needs Assessment (PDNA) for the 2015 Malawi floods reports, among other data, for each affected district, the agricultural area affected, the loss in maize production, the areas harvested with maize and their associated three-year average productions prior to the floods (GFDRR et al., 2015). From the latter two we obtain estimates of the average maize yield in the districts. In this way, dividing the maize loss by the yield, we obtain a quantification of the affected areas harvested with maize. We adjust the maize production loss for one district out of 15, Phalombe, since the original data on maize loss and affected areas result in a much higher yield estimate in affected areas than the average yield for the same district. Specifically, we reduce the Phalombe maize loss to match the total country-level production obtained by our calculations to the one reported by the PDNA. Knowing agricultural affected areas and maize affected areas, we obtain non-maize agricultural affected areas by subtraction. These non-maize affected areas are then allocated to the other affected crops. To do so, we gather the information from the PDNA that the main affected crops besides maize are cassava and rice. In particular, maize, cassava and rice account for 63%, 18% and 9% of production losses, respectively (GFDRR et al., 2015). This means that, analysing these three crops accounts for 90% of the total crop damage, so we exclude further crops from the analysis. We use spatially distributed crop-specific maps of harvested area from the GAEZ database (Frolking et al., 2020) to estimate the district-level relative distribution of the three crops. Data for rice are available separately for rainfed and irrigated conditions, while maize and cassava are not irrigated in the country. Therefore, calculations for rice are carried out separately for the rainfed and irrigated components and aggregated at the end. We assume that the district-level relative distribution obtained from GAEZ maps holds for affected areas in each district. Therefore, we distribute non-maize affected areas in the districts to cassava and rice proportionally to the cassava- and rice-harvested areas. We obtain district-level yield estimates for cassava and rice from GAEZ database yield maps, and use these estimates to compute production losses. We then apply a country-level correction coefficient to crop-specific affected areas, to match the country level productions with the percentages reported by the PDNA. This allows to account for affected areas associated to the 10% of agricultural production losses not pertaining to the three crops included in the analysis. The final result of this procedure is a quantification of agricultural loss in hectares and in tonnes, for each of the analysed crops in each of the affected districts. From these losses, we compute the associated water and food losses. Water losses are computed as agricultural water demand for the affected crops, prior to the floods. To do so, we use the dynamic, physically based, spatially distributed agro-hydrological model WATNEEDS (Chiarelli et al., 2020). The model simulates the water balance in the active layer of the soil for each crop, at a 5arcminute resolution and a daily timescale. The water requirement of the crop is partitioned into green water, i.e. evapotranspiration from precipitation-generated soil moisture and, in the case of irrigated crops such as rice, blue water, i.e. evapotranspiration from soil moisture generated by irrigation water. We run the model from the sowing date of each of the crops in 2014 to January 15th, 2015, i.e. the beginning of the flood event. The cumulation of water demands over this period and on the affected areas is considered as the agricultural water volume lost as a consequence of the floods. To compute food losses, we first separate production losses between losses destined to domestic use and losses destined to export. To do so, we take information on import, export and domestic use of each crop from the FAOSTAT Food Balance Sheets for the average of years 2012-2014 (FAO, 2022), and assume a negligible stock variation for the selected items. Therefore, we calculate domestic losses and export losses for item i in district j as follows:

$$Domestic\ loss_{i,j}[ton] = Loss_{i,j}[ton]\frac{D_i - I_i}{D_i - I_i + E_i} \quad (1)$$

$$Export\ loss_{i,j}[ton] = Loss_{i,j}[ton] - Domestic\ loss_{i,j}[ton] \quad (2)$$

Where D_i, I_i and E_i are average domestic supply, import and export for item i in Malawi between 2012 and 2014, in tonnes. The calculation is carried out analogously for losses in indigenous chicken and freshwater fish, which are reported by the PDNA. We compute food security impacts as people-equivalents of agricultural impacts, deriving food availability impacts (FAvI) from domestic losses and food access impacts (FAcI) from export losses. The fraction of domestic losses used for food is computed accordingly to the distribution, for each item, among food and non-food uses provided by FAOSTAT Food Balance Sheets. This fraction is then converted to food losses in kilocalories using the caloric content of each item. Food availability impacts are then computed in two different ways. First, we compute an overall food availability impact as the total food loss in kilocalories with respect to the district-level per capita caloric consumption provided by the PDNA. The formulation is therefore the following:

$$FAvI1_j[cap] = \frac{\sum_i Food\ use_i[-] \cdot Caloric\ content_i[kcal/ton] \cdot Domestic\ loss_{i,j}[ton]}{Caloric\ consumption_j[\frac{kcal}{cap}/day] \cdot 365days} \quad (3)$$

To account also for dietary imbalances resulting from agricultural losses, besides food losses as a whole, we evaluate the food availability impact also separately by food consumption categories and then aggregate the overall using a limiting factor approach. The food consumption categories are cereals (including maize and rice), tubers (including cassava), meat (including indigenous chicken) and fish (including freshwater fish).

Food consumption fractions for these categories in Malawi are taken from FAOSTAT Food Balance Sheets. The food availability impact is therefore calculated as follows:

$$FAvI2_j[cap] = \max_{k} \left\{ \frac{\sum_{i \in k} Food\ use_i[-] \cdot Caloric\ content_i[kcal/ton] \cdot Domestic\ loss_{i,j}[ton]}{Intake\ fraction_k[-] \cdot Caloric\ consumption_j[\frac{kcal}{cap}/day] \cdot 365 days} \right\} \quad (4)$$

To provide additional insight on the food availability impact with respect to the current food availability situation in the districts, we convert the overall domestic food loss (i.e., the numerator of FAvI1 in Equation 3) to a daily per capita food loss and apply it to the daily per capita caloric consumption, provided by the PDNA for the average of years 2012-2014. We then compare the result before and after the floods with the recommended caloric supply, computed starting from FAOSTAT data on current national caloric consumption and literature recommendations on caloric intake (Willett et al., 2019). In this way, we can assess the food security situation in each district as degree of satisfaction of these recommendations prior to the flood, and provide an estimate of the worsening of the situation after the flood.

The food access impact is computed by converting losses to their economic value instead of their caloric content. The formulation is the following:

$$FAcI_j[cap] = \frac{\sum_i Export\ price_i[US\$/ton] \cdot Export\ loss_{i,j}[ton]}{Food\ expenditures_j\ [-] \cdot Income[\frac{US\$}{cap}]} \quad (5)$$

Where export prices for each item are taken from FAOSTAT and UN Comtrade databases (FAO, 2022; United Nations, 2022), the average per capita income in US$ is obtained from World Bank data (The World Bank Group, 2022), and the food expenditures as income fraction are provided, for each district, by the PDNA.

To give insight on the resilience of Malawi's food system to this type of extreme events, we evaluate land and water availability to compensate for losses in these natural resources as a consequence of the floods. We gather areas available and suitable for agricultural expansion from (Schneider et al., 2022), and we use WATNEEDS (Chiarelli et al., 2020) to compute water scarcity, as the ratio between water demand (accounting for domestic, industrial and agricultural uses) and water availability (accounting for upstream uses and environmental flows).

3. Results

Losses in terms of area, production and water are reported for each item and district in Table 1, Table 2 and Table 3, respectively. Maize results to be the most damaged crop, not only in terms of production, as stated by the PDNA, but also in terms of affected area and water lost, even though it accounts for different percentages across these three dimensions. The 63% of maize production loss with respect to total agricultural production losses translates into a 48% of land loss attributed to maize and into a 73% of water losses determined by maize, meaning that maize is relatively high yielding and water demanding among the damaged crops. As could be expected, the highest intensity in water damage comes from rice, which accounts for 9% of production losses and 24% of water losses, despite being planted slightly later than maize and cassava. Most notably, areas attributed to other crops constitute 43% of the total agricultural affected areas, despite producing 10% of agricultural losses. This discrepancy could at least partially be explained by differences in yield and crop calendars. For instance, crops that are planted in spring and summer are likely not directly impacted in terms of production damages, even though their agricultural areas are affected by the floods. Concerning differences in yields, crops typically grown in Malawi having lower yields than the analyzed crops, and thus likely generating lower production losses on higher affected areas, include groundnuts, pulses, cotton and tobacco. The most impacted districts are Mangochi, Zomba, Nsanje and Mulanje for maize, and Chickwawa for rice. Interestingly Zomba loses roughly 600t of maize more than Nsanje, but almost 800,000m^3 less green water. Such type of comparisons can be done also for other crops and districts, helping understanding differences in natural resources use efficiency within the country. Losses in fish and chicken are also reported in Table 2, while assessments in terms of associated land and water are not performed. While such an assessment for freshwater fish is negligible, for chicken it might be of interest to quantify water and land losses associated to feed production that went to lost chicken. However, chicken breeding in Malawi is extensive by at least 85%, and, in the case of indigenous chicken, it is very likely they are bred in backyards for subsistence, thus relying on hard-to-trace feed sources such as swill, scavenging and other locally produced feeds (Govoni et al., 2021). Concerning freshwater fish, the losses seem to be particularly concentrated in the Zomba district, which, although not being located on Lake Malawi, has a secondary lake, Lake Chilwa, which is the center of a smaller drainage system (The World Bank Group & GFDRR, 2019).

Table 1. Agricultural losses due to the 2015 flood in Malawi, in terms of crop-specific affected areas by district.

	Agricultural loss [ha]				
District	Maize	Cassava	Rice rainfed	Rice irrigated	Other crops
Karonga	0.0	0.0	0.0	0.0	0.0
Rumphi	102.1	0.1	0.1	0.0	1.7
Ntcheu	2723.4	21.9	69.4	3.2	692.2
Salima	594.8	6.3	23.5	0.2	198.3
Balaka	3107.4	303.6	182.5	5.0	9540.5
Machinga	3229.2	183.9	174.1	18.9	5783.9
Mangochi	10598.4	359.2	304.6	11.4	11294.4
Zomba	5269.3	63.0	794.8	39.6	2050.4
Blantyre	804.0	1.3	3.0	0.1	42.5
Thyolo	229.2	0.4	15.8	288.6	38.1
Chiradzulu	47.8	4.2	22.1	0.5	134.4
Phalombe	2908.2	1.5	23.8	10.7	50.8
Mulanje	5070.9	22.7	272.6	1160.6	837.2
Chikwawa	3153.6	97.2	545.0	2767.6	3337.6
Nsanje	5093.4	135.1	0.0	0.0	4238.5
Total	42931.6	1200.4	2431.3	4306.3	38240.3

Table 2. Agricultural losses due to the 2015 flood in Malawi, in terms of crop-specific production losses by district.

	Agricultural loss [ton]					
District	Maize	Cassava	Rice rainfed	Rice irrigated	Freshwater fish	Indigenous chicken

Karonga	0	0.0	0.0	0.0	0	0
Rumphi	148	0.9	0.1	0.0	0	0
Ntcheu	4586	435.2	45.7	7.7	3	0
Salima	1300	174.8	29.3	0.5	0.14	0
Balaka	6878	6859.2	216.5	13.0	0.65	1
Machinga	6989	4207.0	207.4	51.2	0	2.56
Mangochi	21863	7342.3	287.0	30.6	0.53	2.26
Zomba	11407	1182.4	850.1	101.5	20.72	1.72
Blantyre	1579	19.4	2.4	0.4	4.75	9.84
Thyolo	445	3.3	11.7	464.1	1.4	0
Chiradzulu	76	52.3	26.8	1.2	1.3	0.34
Phalombe	5452	24.8	35.7	26.8	0.66	22.47
Mulanje	9228	301.2	337.2	2498.6	3.3	6.98
Chikwawa	7067	1867.7	284.4	7023.0	0.33	4.97
Nsanje	10851	2634.5	0.0	0.0	1.44	53.41
Total	87869	25105	2334	10219	38.22	105.56

Table 3. Agricultural losses due to the 2015 flood in Malawi, in terms of crop-specific associated water losses by district.

	Green Water Loss [m3]				Blue Water Loss [m3]
District	Maize	Cassava	Rice rainfed	Rice irrigated	Rice irrigated
Karonga	0.00	0.00	0.00	0.00	0.00
Rumphi	40,859.25	69.71	83.79	1.89	1.73
Ntcheu	1,310,639.05	33,928.70	62,367.42	2,145.95	1,514.03
Salima	244,429.98	6,606.62	15,877.53	54.04	72.07
Balaka	1,174,757.49	136,840.58	44,872.47	3,406.43	2,433.66
Machinga	1,912,441.31	145,369.47	73,987.35	18,034.06	10,371.42
Mangochi	5,304,291.75	255,361.35	82,984.50	7,175.93	6,363.33
Zomba	2,888,008.82	127,158.43	844,836.96	34,599.80	16,169.65
Blantyre	436,383.94	2,535.23	3,093.59	93.97	48.77
Thyolo	168,271.55	1,031.34	15,136.84	282,059.85	95,571.60
Chiradzulu	26,507.84	8,881.19	24,324.21	608.83	238.26
Phalombe	1,984,247.98	4,171.08	31,451.22	14,907.41	5,267.13
Mulanje	3,241,958.39	60,691.90	230,603.40	1,246,517.93	397,101.91
Chikwawa	2,083,344.09	128,722.67	451,743.32	2,706,616.75	1,155,439.65
Nsanje	3,662,003.58	326,302.92	0.00	0.00	0.00
Total	24,478,145.02	1,237,671.18	1,881,362.60	4,316,222.85	1,690,593.21

Estimations of food security impacts are reported in Table 4, both as people equivalents and as equivalent percentage of the district population. It is evident that food availability impacts are dominant over food access impacts. This is representative of the importance of domestic production for domestic consumption, despite Malawi being a maize exporter in the region. Also, the most impacted district for what concerns food access is Chickwawa, which owes much of its food access impact to losses in rice for export, given also the higher export price of rice with respect to the other crops. Food availability impacts potentially reach more than 300,000 people, almost 4% of the country population in 2015. The most impacted districts are Mangochi, in absolute terms, with a FAvi1 of 70,000 people, and Nsanje, where the FAvI1 corresponds to 12.6% of the district population. Chickwawa locates in an intermediate position between these two districts, with a FAvI1 of approximately 57,000 people, slightly more than one tenth of the district population. Even though looking at results of FAvI1 and FAvI2 as percentages of district populations can help compare impact intensities across districts, these indicators are not bounded to be a fraction of the population they are computed on. Indeed, these indicators can exceed in value the local population when a district produces, and loses, more than it consumes. This happens, for instance, in the FAvI2 value for the Balaka district. In this case, the food loss in cassava is the highest food loss with respect to item-specific food consumption, and it exceeds by 49% the cassava consumption in the district. More in general, FAvI2 values derive from relative cassava and fish losses in most of the cases (7 and 4 out of 15, respectively). This is because these items belong to food consumption categories that occupy relatively low shares of the diet. As a consequence, for the same food loss in terms of total kilocalories, fish and cassava losses are likely to impact the diets of more people than items that are consumed in larger quantities. While cassava can be expected to be more or less easily substituted with other similar food items having similar nutritional intake such as potatoes and sweet potatoes, losses in fish, even though accounting for small shares of the diet, can potentially produce impacts on nutrition security, from both the macro- and micronutrient intake point of view. Overall, while, as previously stated, strictly accounting for food availability losses as in FAvI1 renders a total impact of almost 4% of the country population, using FAvI2 to extend the concept also to dietary imbalances increases the impact to more than one fourth of the population of Malawi at the time of the floods.

Table 4. Food security impact quantifications by district, in terms of affected people equivalents and in percentage of district population. FAvI1 represents Food Availability Impact on total caloric consumption, FAvI2 represents Food Availability Impact on food consumption categories, and FAcI represents Food Access Impact.

District	FAvI1 [cap]	FAvI1 [%]	FAvI2 [cap]	FAvI2[%]	FAcI [cap]	FAcI [%]
Karonga	0	0.0%	0.0	0%	0.0	0.000%
Rumphi	356	0.2%	638.3	0%	0.6	0.000%
Ntcheu	12,510	2.2%	42,618.6	7%	38.0	0.007%
Salima	3,374	0.8%	18,611.8	4%	9.5	0.002%
Balaka	23,123	5.9%	586,055.4	149%	67.9	0.017%
Machinga	24,814	3.8%	311,952.0	48%	62.4	0.010%
Mangochi	70,538	6.9%	567,752.4	56%	135.6	0.013%
Zomba	36,286	4.5%	212,034.3	26%	134.8	0.017%
Blantyre	3,986	0.3%	68,780.7	6%	7.7	0.001%
Thyolo	2,285	0.3%	22,098.0	3%	47.7	0.006%
Chiradzulu	276	0.1%	17,389.5	5%	3.6	0.001%
Phalombe	18,904	4.8%	71,755.8	18%	24.5	0.006%
Mulanje	39,820	6.5%	71,186.3	12%	263.2	0.043%
Chikwawa	51,302	9.5%	125,292.3	23%	433.5	0.080%
Nsanje	35,890	12.6%	178,167.3	63%	25.5	0.009%
Total	323,465	3.8%	2,294,333	26.7%	1,254	0.01%

Analyzing FAvI1 in terms of dietary losses instead of impacted people helps uncover interesting distributional aspects of food losses. The maps in Figure 2 show the percentage of district population with food deficiency, as reported by the PDNA, and the dietary loss, calculated as food loss with respect to the recommended caloric supply. It is evident that districts with higher food deficiency prior to the floods tend also to have higher dietary losses in association to the floods. This holds also when looking at losses in terms of total kilocalories, reported in the graph in Figure 2. This trend provides interesting insight on what could be an example of environmental discrimination. When an extreme event with potential food security impacts occurs, areas and/or groups inherently suffering higher degrees of food insecurity even prior to the event are also the most impacted by the event itself. This is likely because the environmental, institutional, socio-economic and cultural factors producing the higher 'baseline' food insecurity also increase both the food-security related exposure and vulnerability to extreme events. Indeed, poverty rates, constructed from WorldPop (WorldPop, 2015) data as population fraction living with less than 2$/day, reach 71% in affected districts, against a value of 64% in non-affected districts.

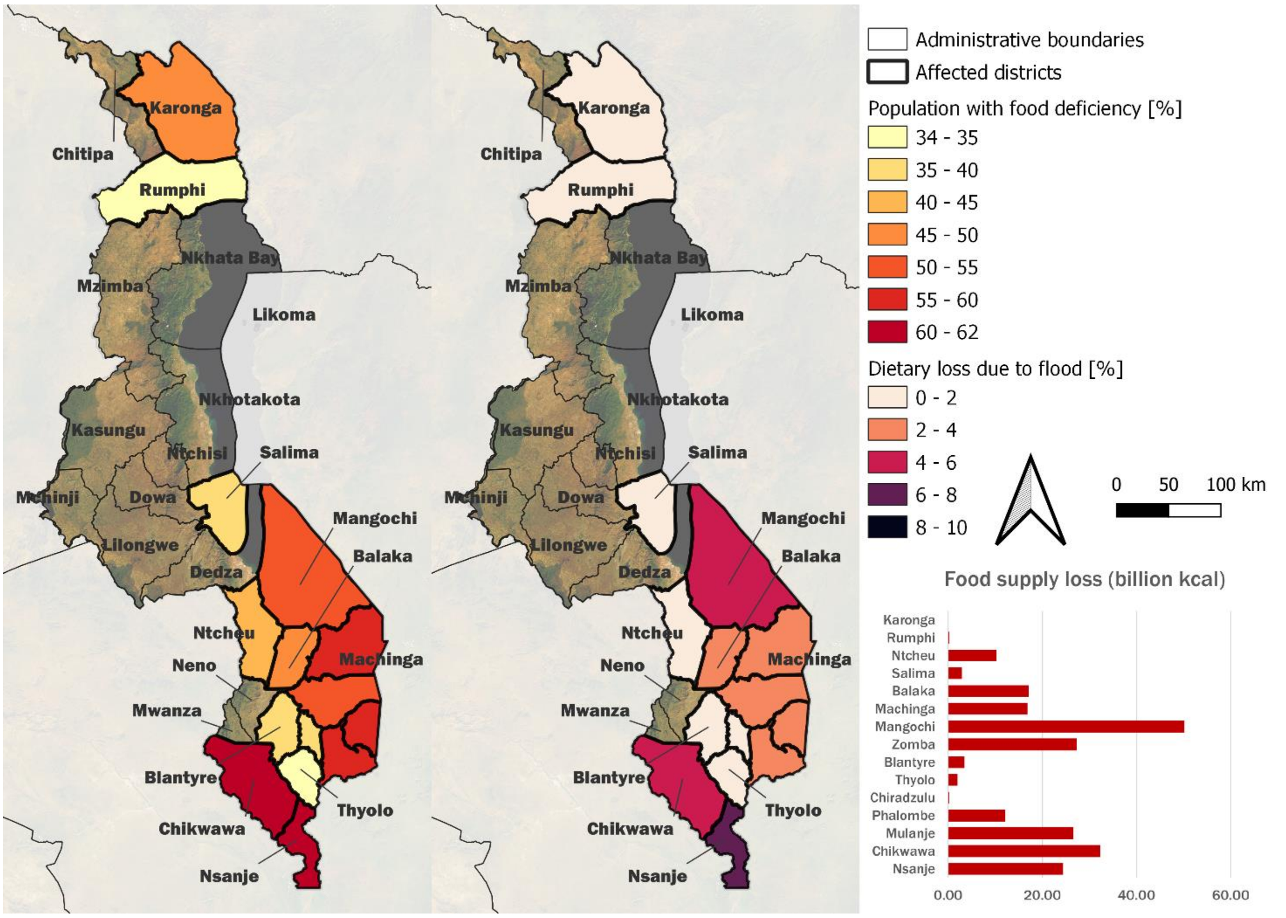

Figure 2. Pre-existing poverty conditions and food supply impacts of the 2015 Malawi floods in affected districts.

Figure 3 provides information on land availability and water scarcity in Malawi, which can be useful to gain insight on the country's resilience to events such as the 2015 floods, and, by extension, on the impacts of such events in terms of food stability. Land available and suitable for agricultural expansion appears to be limited in Malawi, and concentrated in districts both impacted by the flood and in water scarcity often for at least half of the year, such as Salima, Ntcheu, Mangochi, Thyolo and Blantyre. Moreover, heavily impacted districts such as Chikwawa are also districts where agricultural water use produces hotspots of water scarcity, as highlighted by the zoom on the irrigated plot presented in Figure 3. Analogously to the mechanism producing environmental discrimination in food losses, the high agricultural water utilization in this case produces both higher levels of agricultural damage in association to floods and lower availability of resources for environmental resilience.

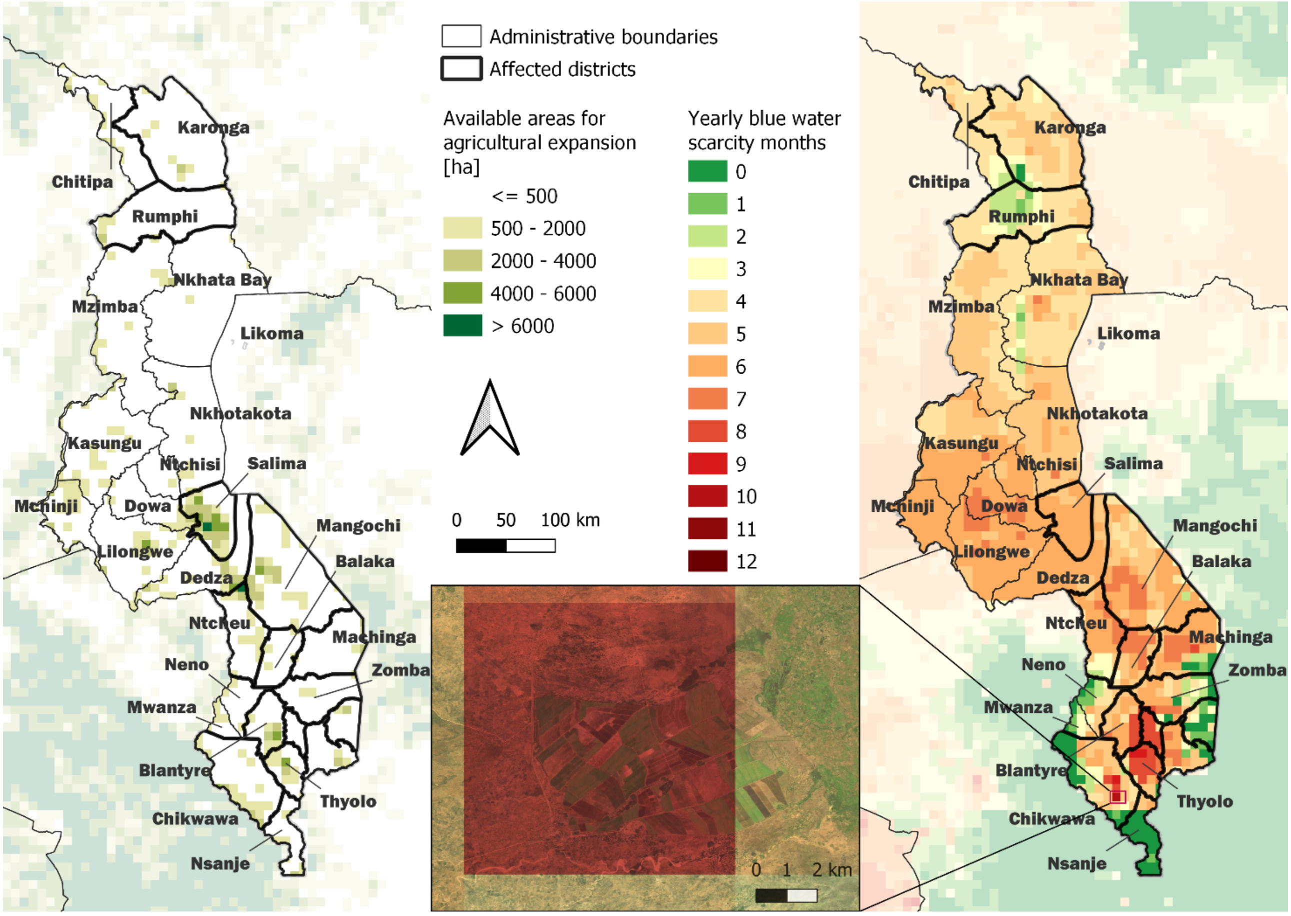

Figure 3. Land and water availability background situation for Malawi.

4. Discussion

In this study, we perform a multi-pillar food security damage assessment of an extreme event, proposing a methodology that has the potential to be easily replicable in other case studies. In fact, the assessment is largely based on data coming either from the Post Disaster Needs Assessment, a global standard for reporting damages associated with natural calamities (United Nations Development Programme, 2013), or from FAOSTAT data, which are available yearly for almost all countries in the world. Moreover, the methodology is relatively simple, ensuring transparency in how the assessments are performed while at the same time allowing for tunings to compensate for uncertainties that can clearly occur in post-disaster assessments. More in general, besides intrinsic uncertainty in the input data, there are some remarks to be made regarding the scope of the analysis. Food availability and food access impact indicators are here introduced as people equivalents. Clearly, these indicators are not a direct representation of the effectively impacted people, rather a proxy of how far-reaching the damage of the flood can be to the local food system. Accounting for food security impacts in terms of people equivalents allows to consistently compare impacts on different pillars while still accounting for the different ways in which damages to agricultural production affect people's livelihoods, depending on whether they are destined to domestic consumption or trade. This could be furtherly deepened and expanded by considering, for instance, how export losses impact not only food access in the exporting country but also food availability in the importing countries, especially those highly dependent on imported goods. Moreover, accounting for internal trade could further refine spatial gradients of food availability and food access impacts. Yet, not considering internal trade can also be an appropriate modeling choice, as it allows to assess the damage where it is produced, rather than where it effectively impacts. This is, for instance, why we can have food availability impacts higher than the local population. When this occurs, it means that the damaged production in the district was most likely destined also to other districts. Knowing this can be key in setting intervention priorities for increasing coping capacity in an effective way, by mitigating risk at the root of the damage propagation chain.

Food security is typically conceptualized into four pillars: availability, access, utilization and stability (FAO & European Union, 2008). Impacts on food availability and food access have been thoroughly analysed in this study, and potential improvements highlighted. Impacts on food utilization and food stability require other types of data and analyses to be assessed in a fully quantitative way. Here we provide qualitative perspectives on how this could be done. Food utilization represents the ability to use available and accessible food effectively, for a balanced diet without associated health risks. In this sense, the losses in chicken and freshwater fish could represent, more than other items, a loss in food utilization, because chicken and fish lost due to flooding are still available from a purely technical point of view, but not utilizable, while crops are typically destroyed before being harvested or ready to harvest. Moreover, fish is a harder to replace food item with respect to the crops considered in the analysis, and the fact that the results of FAvI2 are relatively sensitive to freshwater fish losses are coherent with that. Food stability entails the temporal dimension of food security, considering risks of losing food access as a consequence of specific events (FAO & European Union, 2008). Therefore, in our analysis, food availability and food access impacts could be seen as availability and access declinations of food stability impacts, given that they arise as a consequence of a flood event. Indeed, food stability impacts could reach beyond these effects. To perform a more thorough assessment of food stability impacts, information should be leveraged, for instance, on the recovery time of the food system. Agricultural impacts could go beyond crops directly affected by the flood if, for instance, land and water resources affected by the floods remain unusable for a period of time long enough to delay or preventing the planting of other crops. On the other hand, it would also be important to use information on the human, social and financial capitals available to the affected communities for coping with shocks in the food supply chain (Béné, 2020). These can include measures adopted to compensate for food availability and food access losses, such as changes in import/export fluxes but also humanitarian aids, which, under the right conditions, can be critical in mitigating food stability impacts (Haile, 2005). However, we choose to set the scope of our analysis on the assessment of damages to highlight differences in exposure and vulnerability among the affected districts, while leaving the coping capacity and resilience of Malawi to a more qualitative description. Indeed, we can gain some insight into how the country reacted to this event by looking at temporal trends of imports, exports and production of main agricultural goods in Malawi in the years before and after the floods. For instance, a peak in maize imports emerges from the FAOSTAT Food Balance Sheets, which is not fully explained by the flood impacts estimated for maize production. This is likely due to two reasons. First, maize is likely imported to compensate not only for maize losses, but also for other losses of similar items, e.g., rice and other carbohydrate-rich foods, which might have higher import costs. Second, the FAOSTAT Food Balance Sheets for years 2015 and 2016 include also effects of the major drought that hit Malawian agriculture from October 2015 to March 2016, producing damages across the agricultural sector for 240.7 million US$ (GFDRR et al., 2016). Indeed, compound events such as the floods-drought in Malawi can produce significant impacts on food systems, and thus more research is needed to further address how the marginal effects of single disasters combine in the case of compound events (Mehrabi & Ramankutty, 2019; Singh et al., 2021). In this regard, our methodology is based on reported damage levels from Post Disaster Needs Assessments, and thus it transcends the nature of the extreme event. Therefore, while separating the effects of compound events in terms of food stability might be complex, our analysis allows to evaluate marginal food availability and food access effects of single events, thus potentially aiding in separating, for instance, effects of the floods from effects of the drought. Previous research experiences in food security impact assessment of floods used flood modeling to quantify the damages (Pacetti et al., 2017). This can be a powerful approach for a more spatially refined assessment of damages, even with all uncertainties connected to flood modeling. On the other hand, using damage quantifications from Post Disaster Needs Assessments makes the procedure simpler and more exportable, while also allowing to account for impacts as surveyed on the field instead of impacts as estimated from theoretical or empirical models.

5. Conclusions

The main aim of the study is to provide an efficient and reproducible methodology for deriving innovative and relevant metrics of food security impacts from post-disaster assessments. To do so, we based our food security impact quantification on food security pillars proposed by FAO, adapting the degree of qualitative/quantitative assessment to the available data and to the nature of the pillar, and applied the procedure on the Malawi 2015 floods. We combine spatially distributed data on harvested areas and yields with post-disaster agricultural loss assessments and state of the art hydrological modeling to quantify crop- and district-specific damages not only from the viewpoint of agricultural production, but also in terms of the natural resources exploited for this lost production. By transforming these lost resources into food security impacts as affected people equivalents, we are able to consistently compare effects on food availability and access while highlighting disparities and disproportions in the effects of the floods. In fact, while effects on food availability appear to be stronger than effects on food access, districts with more severe background poverty and food insecurity conditions seem to be hit more by these effects. Moreover, impacts on food security, also including utilization and stability, appear to go beyond resources directly impacted by the flood, involving resource availability for damage compensation and socio-economic resilience and coping capacity. The proposed methodology is therefore flexible to further implementation and testing on other case studies.

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