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Systemic risk and compound vulnerability impact pathways of food insecurity in Somalia

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A R T I C L E I N F O

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A B S T R A C T

In a strongly interconnected world, extreme and compound events pose systemic risks to food security and populations already vulnerable to the impacts of climate change. Pre-existing vulnerabilities can also compound, interfering with adaptation strategies and affecting human migration patterns. While some drivers of compound vulnerability are known on a normative level, there remains a critical gap on the relationship between drivers of vulnerability systemic risk, and food insecurity outcomes. We use a systemic risk impact pathway (SRIP) model to gain data-driven insights on the drivers of systemic risk and the impacts on food insecurity in Somalia. By applying data on extreme weather and food insecure internally displaced populations from 2011 to 2019 we isolate different components of vulnerability and show how they compound and relate to systemic risk drivers. Our findings contribute to the empirical evidence on limits to adaptation indicating that systemic risk impacts compound vulnerabilities and act as adaptation 'roadblocks' for food security. We argue that a systems design can provide guardrails to resilience opportunities where compound vulnerabilities overstretch fragile resilience levels.

1. Introduction

Impacts from extreme weather and compound events become ever-more pronounced, underscoring the food security related vulnerabilities of migrant and displaced populations (Hoegh-Guldberg et al., 2019; Pörtner et al., 2022). Compound events are the result of a combination of factors rather than one single issue that contributes to increased social and environmental risks, stretching population's adaptive capacity and increasing risks of food insecurity outcomes (Raymond et al., 2020; Thalheimer et al., 2022; Zscheischler et al., 2018). To effectively allocate food and humanitarian aid to populations displaced by extreme weather, we need to better understand the drivers of vulnerability and how they compound. Increasingly, evidence on compound events is documented. However, the evidence base on compound vulnerability effects has been severely limited by a hazard-by-hazard approach and methodological challenges disentangling links of vulnerability components and systemic risk drivers (Renn et al., 2019). We provide detailed definitions of compound vulnerability and systemic risk in Supplementary Material SPM B and SPM C.

East Africa is projected to experience extreme dry, wet and compound extremes at exceptional scale with additional impacts from

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climate change (Masson-Delmotte et al., 2021; Thalheimer, Williams, et al., 2021). Resulting cascading risks and their consequences can affect vulnerable populations such as internally displaced populations through vulnerabilities that compound spatially, temporally or both (compound vulnerabilities) (Hoffmann, 2022; Thalheimer et al., 2022; Xu et al., 2020). It is estimated that 162 million people globally are faced with food crisis situations (IPC, 2022). The humanitarian crises in Somalia demonstrate that among many possible vulnerability stressors, extreme dry events and food insecurity are key concerns of climate adaptation (Anderson et al., 2021; Funk, 2020; Kimutai et al., 2023). Compounding vulnerabilities thus represent a grave challenge to Somalia's internally displaced population (IDP) and their ability to secure food with continued warming.

Here we ask: How do vulnerability components compound and how does systemic risk aggravate vulnerability? To decipher this complex risk and vulnerability landscape in Somalia, we map vulnerability components and various ways they contribute to food insecurity as an outcome variable. We show systemic risk effects, using a systems analysis approach. To do so, we draw on data of food insecure IDPs at subnational level across subnational regions in Somalia from 2011 to 2019.

We combine these datapoints with disaster data, carefully isolating each of the vulnerability impact pathways. We list additional details on the country context in the Supplementary Material (SPM A). Thereby, we show how floods, droughts, and storms aggravate food insecurity situations through pathways of compounding vulnerability (see Table 1). We further show that addressing the vulnerability landscape from a systems perspective can contribute to minimizing adverse outcomes of systemic risks. Unlike previous studies, we find impacts from systemic risks and compound vulnerabilities together disrupt formerly effective adaptation strategies in the context of food security.

Our study relates to research on complex risk modeling in socio-ecological systems (Franzke et al., 2022; Ide et al., 2020; Keilbar & Wang, 2021) and research on systemic risk drivers of food security (Gaupp et al., 2021; Nicholson et al., 2020). We also expand the knowledge base on compound vulnerability determinants that can contribute to reducing the impacts of climate change on vulnerable populations. The discussion and conclusion section links to relevant literature around systemic risk, vulnerability, and exposure (McLeman et al., 2021; Richards et al., 2021; Watts, 2016).

Prior research has postulated that societies living in violence and conflict-affected areas are particularly vulnerable to the impacts of climate change (Adger et al., 2014) and that impacts from climate change can act as a conflict promotion drivers (Buhaug, 2016; Hsiang et al., 2013; Koubi, 2019), and exacerbate forced displacement and conflicts over grazing land and other renewable resources (Guldberg et al., 2018). Yet, there has not been full consent on the determinants of risk drivers and its interaction with underlying vulnerabilities (Cardona et al., 2012; Davis et al., 2021). The growing recognition of compound events, vulnerability and systemic risk raises questions on disaster risk reduction implications (Kruczkiewicz et al., 2021; McLeman et al., 2021; Ringsmuth et al., 2022). In this study, we complement this research and contribute a systemic risk impact pathways analysis of the different components of vulnerability, how they compound and their relation to systemic risk and associated drivers. We also provide a definition of systemic risk in Supplementary Material SPM B.

The literature shows that the evidence on the interaction between extreme weather, displacement, and food security in conflict settings is mixed. In natural resource-dependent communities and countries with weak governance like Somalia, climate change impacts could further amplify conflict over scarce natural resources (Ide et al., 2020; Schleussner et al., 2016). One study assessing climate-conflict causal effects finds that direct effects across Africa from warming increase conflict risks. At the country level, however, warming decreases this effect across Western Africa. This effect is masked when considering indirect effects through food and water supply (Helman et al., 2020). In arid regions with protracted civil armed conflict, conflict itself has impaired mechanisms to cope with extreme events and economic productivity (Kelley et al., 2015; Maystadt & Ecker, 2014). As an example for cascading risks, drought and water-stress affected communities, paired with political instability and conflict incidences could find themselves in situations of forced displacement (Adger et al., 2015; Cattaneo et al., 2019; IPCC, 2019; Missirian & Schlenker, 2017).

Impacts of extreme weather, displacement and food security are highly contextual (Anderson et al., 2021; Bjornlund et al., 2022; Koubi, 2019). By analyzing critical system interdependencies that are amplified by underlying vulnerabilities we effectively expand this literature strand. Our setting allows us to carve out individual vulnerabilities and show their compound interactions through impact pathways. Compared to exiting studies, such enhanced evidence is relevant for preventative climate policy and anticipatory humanitarian action to address compound vulnerabilities through preemptive tools such as forecast-based financing mechanism that are implemented or funded at the subnational level.

2. Data and methods

2.1. Disaster data and processing

We draw on open-source data records on weather and climate-related disasters from the EM-DAT, Emergency Events Database

Table 1
Model specifications and impact pathways.

No.	Identified impact pathways	Model specifications	Results
1	Environmental vulnerability and socio-economic vulnerability on food insecurity	channel A + B	Table 2
2	Extreme weather on food security	channel B	Fig. 4b
3	Socio-economic vulnerability and political vulnerability	channel C	Fig. 5
4	Environmental vulnerability and political vulnerability on food insecurity	channel B + D + E	Fig. 4a, Supplementary Material SPM A
5	Compound vulnerability	channels A – E	Fig. 3

(Guha-Sapir et al., 2016). Climatological, meteorological, and hydrological disasters and associated impact events were obtained from 1983 to 2022. Within the database, droughts are 'climatological', floods are 'hydrological' and storms are 'meteorological' disaster subtypes. Each time a disaster occurs, associated disaster impacts are recorded. EM-DAT captures this detailed information at the local level through reports and estimates from UN agencies, non-governmental organizations, and insurance companies, among others. We select associated disaster impacts from the database to carve out disaster complexities including climatological causes. The EM-DAT disaster data (Table 2) shows the distribution of food insecurity and famine occurrences over time. The data also shows that a large portion of the population is affected by drought consecutive flood events.

2.2. IDP priority needs data and patterns

We measure priority needs of associated IDPs through open-source survey data collected by the United Nations High Commissioner for Refugees (UNHCR) initiative Protection & Return Monitoring Network (PRMN) in all of Somalia's 18 subregions at a monthly frequency over 2016–2019 (UNHCR, 2022). Through on-the-ground surveys, PRMN collects statistics on new internal displacements including returns of populations at various points across Somalia. Associated priority needs of new IDPs were originally reported in eight categories: food, water, shelter, livelihood support, health, protection, transport, and humanitarian aid. PRMN does data collection arrival points (destination) by monitoring of internal displacement flows at various locations including transit sites, IDP settlements, border crossings and ad-hoc locations. PRMN carries out interviews with IDPs generating household-level reports at destinations or with key informants generating group reports. Detailed information on PRMN's data collection can be found in the PRMN manual (2017). The visual inspection of the PRMN data shows an emphasis of food as priority need in drought-reported displacement across Somalia. As PRMN records the origin and destination of IDPs, the IDP priority needs and displacement pattern data thus allows us to uniquely model within-region priority needs.

2.3. Systemic risk drivers

Systemic risks drivers are interconnected and include non-linear processes (Fig. 1). Systemic risk assessments account for complexity in the form of multiple underlying drivers and a range of consequences, thereby going beyond individual linear cause and effect relationships (see SPM B). In the context of the interconnectedness from climate change impacts, risks from compound events can result in tipping over food security outcomes. Crop failure in several regions aggravates the risks to food insecurity (Gaupp et al., 2020). Non-linearities include exponential changes or delays and can cause sensitivity to small changes (Helbing, 2013). Crossing

Table 2
Disaster-affected populations and associated disaster impacts, 1983 – 2022.

Time	Disaster	Associated disaster impacts	Reason	Region	Disaster-affected population
1983	Drought	Water shortage	–	northwest	–
1996	Flood	Broken Dam/Burst bank	Heavy rains	–	100
2000–2001	Drought	Food shortage	–	central and southern Somalia	1,200,000
2004	Drought	Food shortage	–	Somaliland, Puntland, central Somalia	200,000
2005	Drought	Food shortage	–	southern Somalia	–
2007	Flood	Broken Dam/Burst bank	Heavy rains	southeast	8,000
2008–2009	Drought	Food shortage	–	central Somalia	3,300,000
2010–2011	Drought	Famine	Failure of Gu and Deyr rainy seasons in 2009	Somaliland, central Somalia	4,000,000
2012	Drought	Food shortage	–	northwest and southern Somalia	3,000,000
2013	Tropical cyclone	Flood	–	northeast	142,380
2014–2017	Drought	Food shortage	Short and poor rainy season	southern Somalia, Somaliland	535,624
2015	Tropical cyclone 'Megh'	Flood	–	northeast	–
2015	Drought	Food shortage	El Niño	Somaliland, Puntland, northwest	4,700,000
2018	Tropical cyclone 'Sagar'	Flood	–	Somaliland, Puntland	228,000
2019	Drought	Food shortage	Dry conditions	Somaliland, northeast	1,500,000
2019	Tropical storm 'Patwan'	Flood	Heavy rains	northeast	30,000
2020	Tropical cyclone 'Gati'	Flood	–	Puntland	120,000
2021–2022	Drought		–	Somaliland, Puntland, southwest	7,100,000
2022	Flood		–	northcentral Somalia	4,416

Note: A '–' indicates that no data is available.

these tipping points can lead to systemic changes or even systems breakdown. Positive feedback can lead to dynamic instability, for example, free-riding behavior such as overexploitation of common goods.

2.4. Systemic risk impact pathway model

2.4.1. Conceptual approach

The relationship between systemic risk drivers and vulnerabilities can affect food insecurity outcomes through multi-directional ways. We use the conceptual framework of impact pathways as the identification strategy in this study (Fig. 2). Environmental vulnerabilities can indirectly affect socio-economic vulnerabilities through poverty and increase food insecure IDPs as shown in channel (A) in Fig. 2, or directly through extreme weather (e.g., prolonged droughts) leading to increased levels of food insecurity (B) and subsequent political vulnerability (D). Conflict may drive food insecurity, for example when people flee a warzone (E). Political vulnerability may be affected by socio-economic vulnerability. This may be the case when ethnic groups mix, intra clan rivalry and resource scarcity (C). We rely on a set of identifying assumptions to investigate individual and compounding impact pathways of vulnerability. First, we assume that the priority need of IDPs are truthfully declared at each PRMN checkpoint, see notes on the data collection in the PRMN (2017) methodology. Second, in the case of Somalia, we assume that pre-existing vulnerabilities exacerbate systemic risk drivers. The literature indicates that although the degree to which people are exposed to and affected by systemic risk drivers differ, risk alone does not cause vulnerability (e.g., Betts et al., 2018; Hansen et al., 2022; McLeman et al., 2021; Richards et al., 2021). We thus consider our assumptions reasonable.

By analyzing how each vulnerability, environmental, political, and socio-economic – interact and impact food insecurity within Somalia, we give empirical insight on five Systemic Risk Impact Pathways (SRIP), indicated as channels (A) to (E) in Fig. 2.

2.4.2. Model specifications and impact pathways

With a focus on Somalia, we synthesize published datasets and literature on the effects of vulnerability and systemic risk drivers and food insecurity outcomes for modelling the SRIPs (Pape & Wollburg, 2019; Thalheimer, Otto, et al., 2021; UNHCR Somalia, 2017; Webersik et al., 2018; World Bank, 2018, 2020a, 2021). These data and literature points include observations from survey-based fieldwork and from expert consultations in the country. We identify the influence of three vulnerability systems at the subnational level in a SRIP model. We model five impact channels through which systemic risk can drive these vulnerabilities, directly and indirectly, and lead to food insecurity outcomes (Table 1).

On the interaction of vulnerabilities (i.e., how these form compound vulnerabilities) and the role of systemic risk drivers, we use disaster and IDP priority needs data to facilitate the application of the SRIPs to our analytical framework. These impact pathways draw on other qualitative modelling approaches such as ‘impact flow diagrams’ (Guijt, 1998) and ‘outcome mapping’ (Smutylo, 2001). Impact pathways identify sequences that are able to explain a specific change process (Springer-Heinze et al., 2003) and can be complex (Herrero et al., 2021). Starting from exogenous variables, e.g., extreme weather events, SRIPs visually outline causal links and

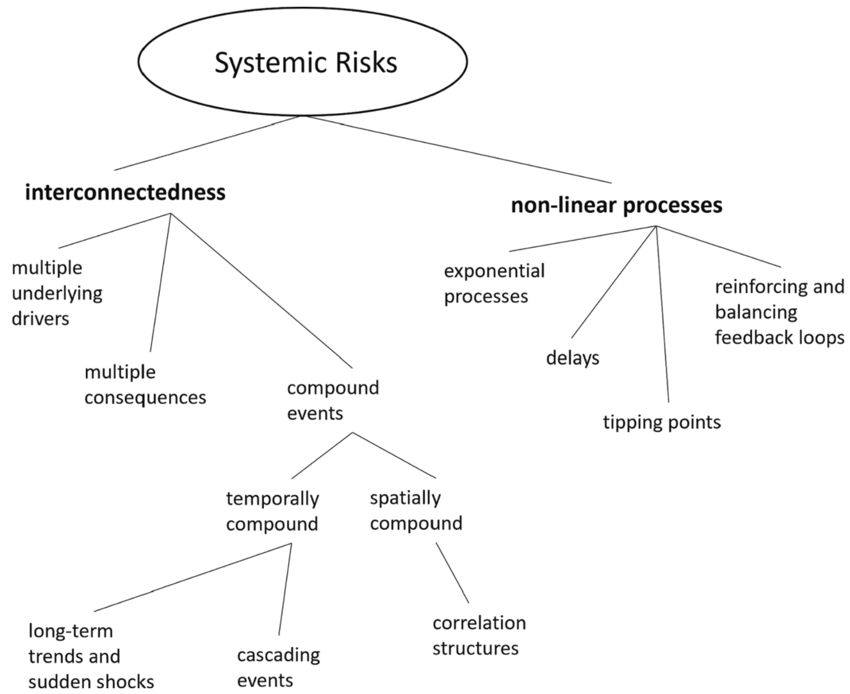

Fig. 1. The Systemic Risk Impact Pathways model includes interconnected risk drivers and non-linear processes as systemic risk elements.

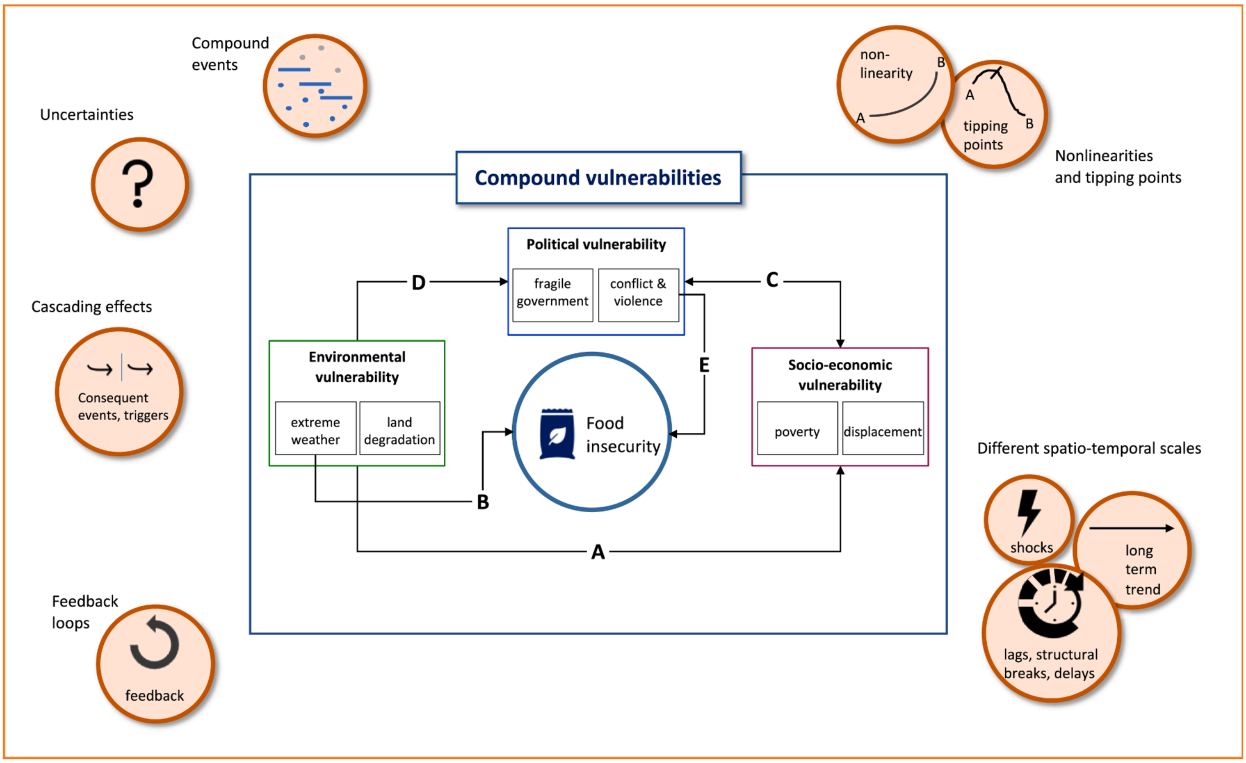

Fig. 2. Concept of impact pathways concept system; the relation between environmental, political, and socio-economic vulnerabilities, where systemic risk drivers (orange icons) exacerbate compound impacts from political (blue box), environmental (green box) and socio-economic (red box) vulnerabilities, and food insecurity outcomes. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

impact chains that lead to endogenous outcome variables, e.g., food insecurity. Our impact pathways definition includes all types of systemic risk drivers (see Fig. 1) and is therefore well suited to describe compound and complex problems. In the SRIP model, feedback loops or tipping points between the vulnerability causal linkages illustrates the intersection of systemic risk drivers and compound vulnerabilities.

In the context of the SRIP model, we deem the specification of several aspects important: (i) purpose, (ii) model boundaries, (iii) a time horizon, and (iv) the level of aggregation.

(i) The rationale of our analytical framework is to demonstrate how systemic risk drivers exacerbate environmental, socio-economic, and political vulnerabilities compound in Somalia and lead to food insecurity.

(ii) The analysis focuses on Somalia as a country. Exogenous or context variables include hazards such as extreme weather events, long-term trends such as population growth or elements that lie outside of the scope of Somalia such as globalization and colonialism. The outcome variable is food insecurity within the country.

(iii) To obtain a full picture of underlying vulnerabilities driving food insecurity in Somalia, a multi-year time horizon is required. Reflecting the time scale of the literature reviewed, the time horizon of the framework applied reflects in-country expert consultations in 2018 and 2019 (World Bank, 2020a), observations on political instabilities and conflict since the 1990s, drought occurrences and the use of natural resources since the 1980s.

(iv) By setting Somalia as the boundary, the logical level of detail in our framework is national with only exogenous variables describing global challenges.

Linking to the conceptual work of McLeman et al., (2021), we apply a risk lens to unpack components of vulnerability and risk. We built on this previous work on impact pathways of food insecurity (e.g., Hansen et al., 2022) by adding systemic risk drivers, their influence on compound vulnerabilities, and reinforcing feedback loops between vulnerabilities (orange elements in Fig. 2). This allows us to build a toolset to respond to multiple hazards affecting vulnerable populations such as migrants and displaced populations. Previous studies on systemic risk drivers typically use conceptual models or rely on national-level data (Kruczkiewicz et al., 2021; Nicholson et al., 2020; Renn et al., 2019). However, both approaches have limitations despite their merit: National-level data mask within-country variations and thus may miss local effects, whereas conceptual models remain of hypothetical nature. Neither approach is suitable for the purpose of this case study.

3. Results

3.1. *Compound vulnerabilities in Somalia*

Applying our conceptual framework (see Fig. 2), we categorize and map systemic risk drivers (see Fig. 1) to show the interaction between risk elements, environmental (green), socio-economic (red), and political vulnerabilities (blue) vulnerability, and food insecurity outcomes (Fig. 3). We find that almost all exogenous (orange) determinants influence each of the vulnerability pathways directly, and food security indirectly. Population growth contributes directly to food insecurity and indirectly, by raising food demand to fragile food security as an outcome. The increasing frequency and severity of extreme weather has a delayed impact on the environment through land degradation. By contrast, shocks from floods and droughts have an immediate effect on crop productivity levels, crops failures, and strain overall food security.

Furthermore, we are interested in environmental and political vulnerability pathways that lead to food insecurity (channels B and D + E in Fig. 2). We first investigate impacts from colonial structures on food insecurity outcomes (Fig. 4a). We find that colonial influences and increasing market liberalization trends have been drivers of Somalia's political instability and weakening of institutions that formed a vulnerability cycle that have led to conflicts over the last decades and contributed to the collapse of state power (Bjornlund et al., 2022; World Bank, 2018). Export-oriented colonial agricultural production extracted resources to meet the demand in the Global North instead of prioritizing food security in Somalia. Research and investments in agriculture were neglected. In addition, colonialism had undermined traditional social structures such as trust in traditional leaders or the communitarian Somali tradition that had played an important role in tackling food insecurity (Webersik et al., 2018). These political and conflict vulnerabilities are linked to socio-economic vulnerabilities (channel C in Fig. 2) such as the development of a war economy that cascaded into depletion of wealth and poverty. Poverty in turn is one driver of food insecurity as it directly contributes to a lack of food access. Next, we investigate the impacts from extreme weather on food insecurity (Fig. 4b and channel B in Fig. 2). An increasing number of extreme weather events in the long term with some delay, can lead to land degradation and low productivity due to factors such as deteriorated soil quality in drylands (Stavi et al., 2021). In the Somalia context, we find that land degradation has led to vegetation loss, limiting the primary feeding source for livestock (World Bank, 2020a). These environmental vulnerabilities have socio-economic impacts such as rising food prices that drive food insecurity when food becomes unaffordable to many. Although this SRIP describes slow changes over time, food prices and food insecurity can suddenly spike if another drought or flood event hits an already vulnerable system (Fig. 4b). Somalia is projected to have an increase in extreme wet events. The country is also affected by an increasing trend in heat extremes affecting a variety of sectors including political vulnerabilities (Thalheimer, Williams, et al., 2021), see channel D in Fig. 2. In the subsequent result sections, we present the analyses from vulnerability data (disaster and IDP priority needs data), referring to the role of systemic risk drivers in the SRIP model. Through these spotlights, we provide a nuanced picture of vulnerability and adaptive capacity to avoid food insecurity amidst the challenges the population faces across Somalia.

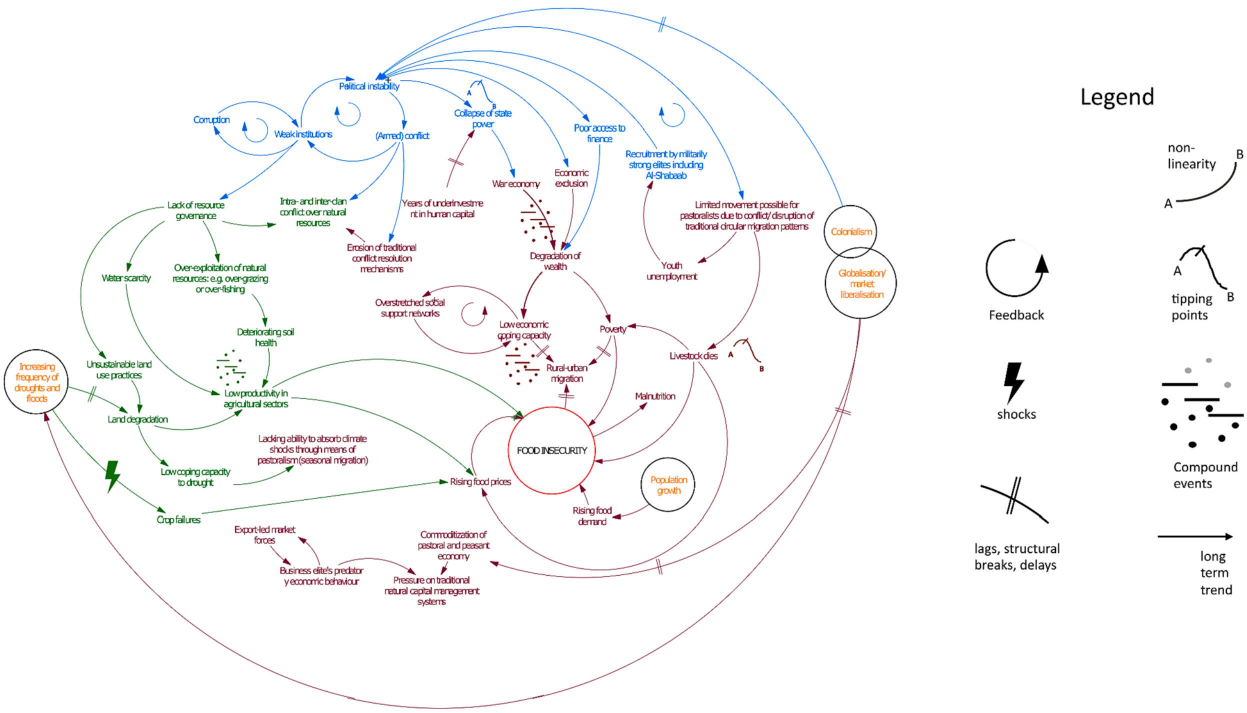

Fig. 3. Systemic Risk Impact Pathways (SRIP) model shows the landscape of compound vulnerabilities and systemic risk drivers in the context of food insecurity in Somalia.

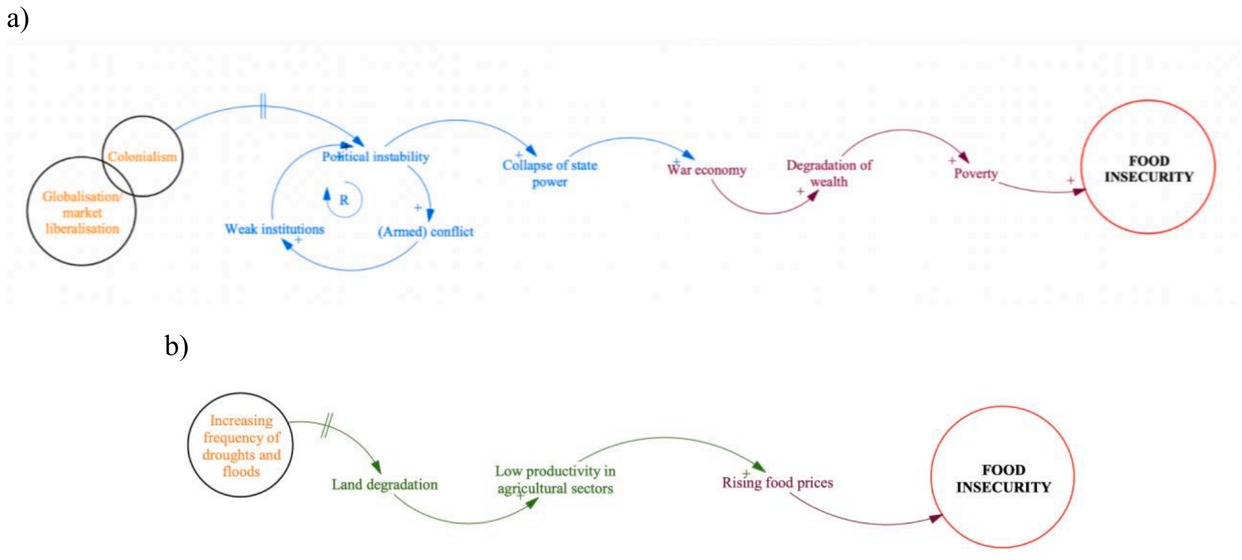

Fig. 4. Systemic risk pathways of a) political and b) environmental vulnerabilities. Note: '+' symbolizes a positive relationship between variables. 'R' indicates a reinforcing process. The double dashed line indicates lags, structural breaks, and delays.

3.2. Impact pathways of environmental vulnerabilities

In recent years, recurring droughts across Somalia have led to critical levels of food insecurity (Anderson et al., 2021; Kew et al., 2021), see channel B in Fig. 2. The EM-DAT disaster data (Guha-Sapir et al., 2016) counts nine droughts between 1980 and 2010; four additional droughts occurred between 2010 and 2022 that are associated with food shortages (see Table 2). However, extreme weather alone has not led to compound vulnerabilities: Severe droughts and famines have coincided with numerous incidences of conflict and political instability – a pattern that could well continue with climate change (Gleditsch & Nordås, 2014). The country's arid climate provides limited natural resources for Somalia's mobile pastoralists and has ramifications for the country's economy (World Bank, 2018). With recurring and prolonged droughts, the capacity to absorb shocks with pastoralist mobility to avoid natural and social

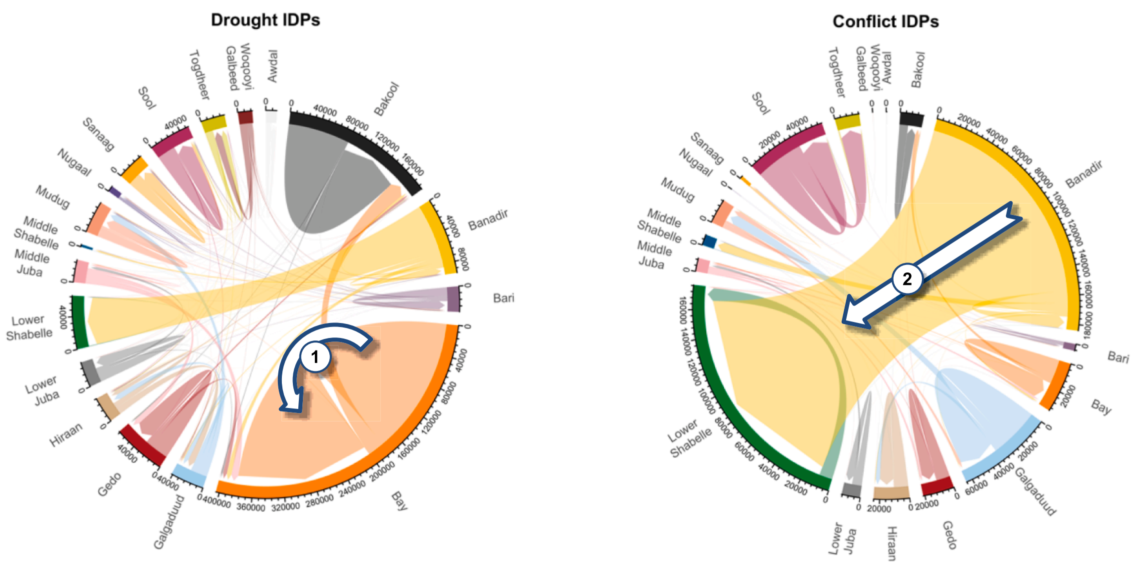

Fig. 5. Regional distribution of food as a priority need of drought affected (left panel) and conflict affected (right panel) IDPs from 2016 to 2019 across Somalia's 18 regions.

hazards is limited (Puma et al., 2018). Effects from armed conflict impacts and limits where pastoralists move to and is closely related to political and conflict vulnerabilities (green and blue arrows, Fig. 3).

In African drylands, the drivers of human mobility are complex and interrelated with environmental factors being one of the many drivers (Hoffmann et al., 2020). From 11.1 million new IDPs in 2020, 4.3 million can be linked to extreme weather events (Internal Displacement Monitoring Centre, 2021). Drought events can lead directly (see channel A in Fig. 2) and indirectly to displacement through conflict and violence (channel C in Fig. 2), although this relationship holds only for certain countries and time periods (Abel et al., 2019). Extreme weather-related displacement is likely to increase in African drylands with additional warming (Hoffmann, 2022; Thalheimer, Williams, et al., 2021).

In the Somalia context, people can be internally displaced from drought affected areas towards conflict areas, creating cascading impacts from environmental vulnerably (UNHCR, 2022). Visually inspecting the IDP priority needs data confirms that food is the dominating priority need among conflict, and extreme weather reported IDPs. However, food needs differ spatially across Somalia. Food needs manifest in southern regions, less so in the northern region, e.g., Somaliland, a region that tends to be politically more stable compared to the southern region (Pape & Wollburg, 2019). We observe a within-rural displacement trend in Southern Somalia, for example, within the Bay region (see 1 in Fig. 5) and an urban to suburban displacement trend (see 2 in Fig. 5). For example, displacement within and from the Banaadir region, where the capital Mogadishu is located, to the surrounding area of Lower Shabelle in southern Somalia. Over 180,000 conflict affected people displaced from Banaadir to neighboring Lower Shabelle are in need of food as primary humanitarian need.

3.3. Impact pathways of socio-economic vulnerabilities

The Somali economy roots in livestock and crop production forming the backbone of its economic performance. The agriculture value-added as a percentage of total Gross domestic product (GDP) was 65.5% in 1990 and the GDP share remains above 60% in 2012 (World Bank, 2018). Rain-fed agriculture in situ makes water a crucial resource for livestock and nomadic pastoralism. Since the 1960s, severe droughts have contributed to the unsustainable use of already limited natural resources such as water and grazing land for livestock (Ajuang Ogallo et al., 2017). Somali pastoralists use circular migration, a form of temporary and often repetitive movement between home and host areas, as a traditional response mechanism to rainfall variability. In the absence of extreme weather, migration patterns coincide roughly with the geographical clan distribution and cross-political borders (Lindley & Hammond, 2014; Mehrabi et al., 2020). Pastoralists' viability depends on the ability to migrate with their livestock to adequate pastures year-round. As a result of extreme weather and conflict shocks, pastoralists change their migration patterns, moving into unfamiliar, non-clan-family territories, facing hostile situations. Sharing common resources among Somali rival clans becomes an exception to the norm with conflict easily turning to violent acts. Already, altered migration patterns towards the west resulted in competition over already scarce pasture and water resources during the 2011 East African drought (Mueller et al., 2020). In Somalia, poverty and population growth contribute to unsustainable land management practices, whilst exacerbating the on-going adverse effects of drought on land productivity (Pape & Wollburg, 2019), see channel C and D in Fig. 2. The EM-DAT disaster data confirms that extreme events occur frequently and can even spatio-temporally compound. Drought have contributed to large-scale internal displacement in recent years. Droughts have affected an estimated 8.6 million people between 2019 and 2022 (Table 2).

Compound vulnerabilities force vulnerable populations to travel further for food and water collection (red arrows in Fig. 3). A trend that has been persistent since the collapse of the Barre regime in 1991. The collapse also contributed to the decrease in agricultural output (Lewis, 2015). Whilst the longest drought in 40 years, Somalia is still recovering from the aftermath of the 2011 East African drought. The 2011 drought caused crop production levels to collapse (World Bank, 2020b). The drought led to a famine that struck Southern Somalia and affected 3 million people and an additional 4 million people in 2012 (see Table 2). Two of these regions coincide with IDP regions in need of food assistance (see Bay and Lower Shabelle in Fig. 5).

4. Discussion and conclusion

We have systematically assessed different drivers of compound vulnerability and their relation to systemic risk in Somalia through a content analysis and a systemic risk impact pathway model. The main result can be summarized as follows: Environmental vulnerably driven by increasing extreme weather events combined with the impacts from and exposure to systemic risk drivers create an exceptional level of risk for food security and livelihoods in Somalia. We illustrate how the current food crisis brings leverage to bear additional instability to an already fragile country.

Using open-source data sets and literature, the systemic risk impact pathways model shows how lags, structural breaks, and delays (i.e., systemic risk drivers) affect environmental, political, and socio-economic vulnerabilities on subnational level and can lead to food insecurity outcomes. Regarding these interlinkages, we find that resulting impacts from systemic risks drivers and compound vulnerabilities disrupt the formerly effective adaptive strategy of seasonal migration to maintain food security. We confirm findings of studies conducted on a single vulnerability variable (Afifi et al., 2014; Betts et al., 2018; Rademacher-Schulz et al., 2014). However, this might be explained by the level of analysis: our analysis includes both national and subnational levels, which shows the spatial clustering of compound vulnerability. The level of granularity in the analysis can thus uncover spatial and temporal patterns of compound vulnerability that provide key entry points for early interventions. However, a system visualization tool may not capture different temporal and feedback aspects needed for the development of intervention points. We overcome this limitation by drawing on a conceptual framework that links agriculture and food insecurity. Nicholson et al. (2020) suggest that system models support the understanding of complex linkages between a singular variable affecting food security. We expand their framework by assessing the potential sources of compound vulnerability affecting food insecurity using subnational data on environmental, socio-economic, and political and conflict vulnerability at different time scales. By showing that compound vulnerabilities prevail and once compounded systems are hit by a shock, systemic risk drivers realize, we can broadly confirm the conceptual findings of Nicholson et al., (2020) in a very different context. Our findings show that an improved understanding of causal relationships of individual links and feedback loops can support risk analyses as part of early and anticipatory actions (Richards et al., 2021).

We find that extreme weather and prolonged extreme dry conditions lead to sustained food insecurity through disruptions of pastoralist mobility patterns. As a result, pre-existing vulnerabilities such as poverty and conflict compound. With the SRIP model, we show that these compound vulnerabilities drive various humanitarian needs of IDPs. Compound vulnerabilities affect the mobility direction of IDPs, limiting their agency and movement and ability to return. In areas where conflict has ceased, or extreme weather has relented, displaced populations are reluctant to the idea of return migration because of limited of food and social service supplies, and livelihood opportunities at origin areas. This has led to dependence on often- underfunded food and aid services (von Braun et al., 2021). Political fragility is a systemic risk driver with a multitude of external factors having led to the protracted conflict, e.g., the inference of outside political powers, youth unemployment, limited economic growth opportunities, political corruption, and armed conflict. Food insecurity can be catalyzed by conflict between armed groups in low social resilience settings, e.g., as a result of droughts paired with limited livelihoods, political elites and illegal tax collections by armed groups.

We acknowledge the various data limitations of our study. For Africa, the EM-DAT database provides a record of droughts, floods and floods, but does not include a full record of heat-associated disasters (Harrington & Otto, 2020). As our variable of interest is food insecurity, we believe we have covered the most relevant associated disasters in the context of drought and relevant to policy implications for our study. As an additional caveat, only information on the primary needs of IDPs is available via the PRMN dataset, not accounting for additional or secondary needs.

In light of the IPCC framing of vulnerability (Pörtner et al., 2022), this research suggests that the increased complexity and compounding nature of vulnerability described could provide a basis for greater leverage of funding for proactively anticipating intervention points, rather that responding after disasters have occurred. In the food insecurity context, anticipatory humanitarian action such as forecast-based financing tools present a suitable funding opportunity to reduce vulnerability (Coughlan de Perez et al., 2019). Another avenue are targeted emergency responses as a first phase of interventions such as building systemic resilience through funding mechanisms such as social safety nets, e.g., small cash transfers and school feeding programs targeted to vulnerable and at-risk households. For this, emergency crop and livestock asset protection provide a practical step. In the anticipatory action context, it has been shown that the provision of climate-resilient feeding, veterinary care, and water supply in pastoralist areas can effectively help prepare vulnerable populations to severely cold winters (*dzud*) in Mongolia (Gros et al., 2020). Cash given prior to natural hazards materializing has also enabled vulnerable households to bridge unexpected gaps in food consumption. Given the Somalia compound vulnerability context, limited options are feasible. Early and anticipatory actions, and social safety nets could be an initial step towards leveraging agency for vulnerable populations. However, an implementation of such programs on the long term is confronted with a seemingly growing and complex risk landscape. From a risk modelling perspective, we deem several caveats as important to highlight: Even though the SRIP model provides some entry points for intervention, limitations remain in obtaining real-time information on estimates, location, and types of vulnerabilities of IDPs to meet the immediate food-related humanitarian needs, as well as resettlement processes. In difficult to access areas such as Somalia, remote sensed data offers an opportunity to augment ground-collected data with the aim to identify receiving locations of IDPs, as well as targeted and priority intervention (Heslin & Thalheimer, 2020). Such information could be used for building risk awareness to compound vulnerabilities and events, reduce vulnerabilities and thereby supporting the capacity building and agency of populations in vulnerable areas.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data are open source. We list our data in the data availability statement in the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.crm.2023.100570.

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