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Caught Between Extremes: Understanding Human-Water Interactions During Drought-To-Flood Events in the Horn of Africa

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Key Points:

- Integration of semi-quantitative and qualitative methods in a bottom-up approach enhance understanding of dynamic event interactions
- Flood and drought events do not act in isolation and fragile contextual conditions further aggravate their impacts
- The close succession of drought and heavy rainfall triggers mechanisms that can increase or decrease disaster risk, both in time and space

Supporting Information:

Supporting Information may be found in the online version of this article.

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Abstract Disaster risks are the results of complex spatiotemporal interactions between risk components, impacts and societal response. The complexities of these interactions increase when multi-risk events occur in vulnerable contexts characterized by ethnic conflicts, unstable governments, and high levels of poverty, resulting in impacts that are larger than anticipated. Yet, only few multi-risk studies explore human-environment interactions, as most studies are hazard-focused, consider only a single-type of multi-risk interaction, and rarely account for spatiotemporal dynamics of risk components. Here, we developed a step-wise, bottom-up approach, in which a range of qualitative and semi-quantitative methods was used iteratively to reconstruct interactions and feedback loops between risk components and impacts of consecutive drought-to-flood events, and explore their spatiotemporal variations. Within this approach, we conceptualize disaster risk as a set of multiple (societal and physical) events interacting and evolving across space and time. The approach was applied to the 2017–2018 humanitarian crises in Kenya and Ethiopia, where extensive flooding followed a severe drought lasting 18–24 months. The events were also accompanied by government elections, crop pest outbreaks and ethnic conflicts. Results show that (a) the highly vulnerable Kenyan and Ethiopian contexts further aggravated drought and flood impacts; (b) heavy rainfall after drought led to both an increase and decrease of the drought impacts dependent on topographic and socio-economic conditions; (c) societal response to one hazard may influence risk components of opposite hazards. A better understanding of the human-water interactions that characterize multi-risk events can support the development of effective monitoring systems and response strategies.

Plain Language Summary Floods preceded by severe drought have often led to greater than expected impacts in the past, especially when it occurred in highly vulnerable socio-economic contexts. Underestimation of these impacts is mainly due to a lack of understanding of how societal and physical systems interact during consecutive risks. In this study, we developed a bottom-up approach, in which we first identified the impacts and then identified potential societal/physical drivers by reconstructing possible interaction paths between impacts, physical and social factors, risk components and response measures. We combined different evidence types extracted from qualitative and semi-quantitative methods to provide a comprehensive narrative of the interactions between physical and societal systems. The approach was tested for the 2017–2018 humanitarian crises in Kenya and Ethiopia, where a rapid drought-flood transition was accompanied by government elections, crop pest outbreaks and ethnic conflicts. Results show a tight interaction between drought and flood risk components (i.e., hazard, exposure, vulnerability), and between them and the respective societal response. This study reveals the complexity of real-world disaster risks and highlights the need to account for spatiotemporal interactions between societal (e.g., conflict) and physical (e.g., drought) events when forecasting impacts and designing effective response strategies to multiple disasters.

1. Introduction

The absolute socio-economic damage from natural hazards has been increasing in recent decades in many parts of the World (Formetta & Feyen, 2019; IFRC, 2020b; IPCC, 2021), resulting in numerous humanitarian crises. These socio-economic impacts have often been attributed to a single hazard event (e.g., drought, flood, cyclone) combined with static exposure and vulnerability conditions (Ciurean et al., 2018). In reality, these impacts are often the result of complex dynamic interactions between societal and physical drivers tightly interlinked with the

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socio-economic and environmental context in which they occur (Ciurean et al., 2018; Gill & Malamud, 2017). Key examples are drought and flood events, which are strongly connected to physical and societal processes that happen across space and time. Interactions between drought and flood hazards (Brunner & Gilleland, 2021), their impacts (Kreibich et al., 2019) and societal responses (Ward, Blauhut, et al., 2020; Ward, de Ruiter, et al., 2020) can lead to severe societal, ecologic and economic damage, particularly if such hydrological extreme events occur in close succession. Drought-to-flood events (i.e., drought followed by flood) not only result in severe impacts (Henn et al., 2020), but may often require larger risk reduction efforts compared to independent drought or flood events (Brunner et al., 2021; Di Baldassarre et al., 2017; Henn et al., 2020; Mazzoleni et al., 2021; Ullrich et al., 2018).

The interplay of consecutive hydrological extremes and the societal system increases in complexity in highly vulnerable contexts, where conflicts, weak institutional capacity, high levels of poverty, social inequalities, and gender/racial disparities can affect human-water interactions (Cutter et al., 2003; Katuva et al., 2020; Peters et al., 2019; UNDRR, 2019). In Colombia, for instance, the drought-to-flood event between 2016 and 2018 was accompanied by continuous violence perpetrated by guerrillas and resulted in the displacement of thousands of families (European Commission, 2020). Over the same period, and again in 2019, drought-to-flood events compounded with extreme poverty in the Indian states of Kerala, Karnataka, Maharashtra and Gujarat, resulting in livelihood losses, population displacement, and an increase in food insecurity (Das, 2019). In the Horn of Africa, between 2016 and 2021, abrupt shifts from drought to flood events coincided with the upsurge of crop pest outbreaks and more recently the COVID-19 pandemic and ethnic conflicts, destabilizing the economy (Kassegn & Endris, 2021; Pott, 2020).

Over the past two decades, a growing number of studies from the socio-hydrology community have explored interactions and associated feedback mechanisms between hydrological and societal processes that occur during either drought or flood events (Blair & Buytaert, 2016; Konar et al., 2019; Pande & Sivapalan, 2017). For drought, a range of studies have investigated how human interventions (from water management strategies to local adaptation measures) influence drought risk through changes in hazard, exposure or vulnerability (Van Loon et al., 2016; Wens et al., 2019). For floods, many more studies are available, with a predominant focus on the dynamics of the human-water system (Barendrecht et al., 2017; Di Baldassarre et al., 2013; Garcia et al., 2020; White, 1945). Only a few recent studies have started to analyze socio-hydrological dynamics between drought and flood events (Di Baldassarre et al., 2017; Mazzoleni et al., 2021; Ward, Blauhut, et al., 2020; Ward, de Ruiter, et al., 2020). These studies primarily focus on the coevolution of societal responses and hydrological extremes, carrying out extensive literature reviews of past events (Ward, Blauhut, et al., 2020; Ward, de Ruiter, et al., 2020) or simulating identified interactions through system-dynamics models (Mazzoleni et al., 2021). Yet, these studies mainly focus on water management (mainly reservoir operating rules) or disaster risk reduction measures, and tent not to consider the biophysical, socioeconomic and political context and events. The concurrence of these events/context with hydrological extremes may influence the impact chains and disaster response strategies, leading to dynamic changes in drought and flood exposure, vulnerability, and hazard.

In this paper, we carry out a retrospective analysis of humanitarian crises related to drought-to-flood events in highly vulnerable socio-economic contexts. Specifically, we ask: (a) What are the physical and social factors that characterized the humanitarian crises under analysis?; (b) How did these factors interact with each other? and (c) How did interactions and feedback mechanisms vary over time and space during these drought-to-flood events? To address these questions in a real-world context, we first proposed a new conceptualization of multi-hazard situations accounting for multiple natural hazard types, societal processes, and a range of interaction types. We then used a bottom-up approach in which impacts were identified first and then underlying variables, processes or phenomena were identified from the impact analysis (Zscheischler et al., 2020). Since impacts are ultimately felt by stakeholders, their perspectives can help to determine the nature of the hazards and their associated spatial and temporal scales (Leonard et al., 2014). Stakeholders can also trace the connections between societal and physical events down to impacts, while also providing information on the types of feedback (Raymond et al., 2020). Accordingly, we used qualitative and semi-quantitative methods in an iterative way. Specifically, we conducted a time series analysis on various hydrological and socio-economic data, performed a semi-quantitative review of peer-reviewed and gray literature, and carried out online surveys and semi-structured interviews.

We tested this bottom-up approach for two case studies in the Horn of Africa in which a humanitarian crisis occurred in 2017–2018. During that time, the rapid transition from the 2016–2017 drought to the 2018 March-May floods was accompanied by conflict and political instability in both Kenya and Ethiopia. An improved understanding of the drivers and socio-hydrological processes that characterized past drought-to-flood events can help us to better understand related future risks of consecutive hydrological extremes and their interactions with the societal system. Before presenting the Methodology (Section 4), Results (Section 5), and Discussion (Section 6) of our study, we discuss the research gaps and present a new conceptualization of interactions during multi-risk events (Section 2), followed by a description of the case studies (Section 3). The definitions of all terminology used in this study are summarized in Table S1 in Supporting Information S1.

2. Rethinking Disaster Risk Domains and Dynamic Interactions

While notable progress has been made in compounding, cascading and multi-hazards research (de Ruiter et al., 2020; Gill & Malamud, 2017; Zscheischler et al., 2020), recent methods and frameworks for disaster risk assessment do not often account for human-water interactions and their spatiotemporal variations (with Mazzoleni et al., 2021 as notable exception). To overcome this knowledge gap, a series of challenges need to be addressed.

The first challenge is linked to the **limited understanding of dynamic changes/feedbacks within and between risk components.** Current risk models account for temporal changes in hazards (Alfieri et al., 2017; Hirabayashi et al., 2013) but this is rarely the case for exposure and vulnerability (Tabari et al., 2021; Ward, Blauhut, et al., 2020; Ward, de Ruiter, et al., 2020). Most studies on multi-risks consider vulnerability and exposure as static (Ciurean et al., 2018; Gallina et al., 2016; Tilloy et al., 2019). However, during long drought events, exposure to flood and drought might change differently (e.g., as a result of migration toward water sources), as well as vulnerability (e.g., as a result of societal dynamics and cascading impacts; Hagenlocher et al., 2019). For instance, in Dakar (Senegal) migrants populate zones at high risk of flood to escape drought and poverty (Ward, Blauhut, et al., 2020; Ward, de Ruiter, et al., 2020). In Brisbane (Australia), flood risk perception decreased during the millennium drought, leading to a rapid development of the flood-prone areas (Bohensky & Leitch, 2014). During drought-to-flood events, these spatiotemporal variations become more complex as we need to understand the dynamics of vulnerability and exposure between different types of hazards (de Ruiter et al., 2020). Furthermore, the dynamic interactions between hazards have been explored primarily in relation to the increase of the overall risk and related impacts. However, simultaneous and consecutive hazards could also lead to the mitigation of overall impacts (Hillier et al., 2020). For instance, a snow drought in Afghanistan in the winter of 2018/2019 resulted in a rapid increase in food insecurity and a decrease in vegetation and soil absorption that exacerbated both flood vulnerability and hazard once heavy rains occurred in March–April 2019 (Huning & AghaKouchak, 2020; IFRC, 2020a). On the other hand, during the Australian millennium drought (2001–2009), drought conditions led to changes in the rainfall-runoff relationship in many basins, resulting in less than expected runoff due to evaporation (Peterson et al., 2021) and/or increased soil infiltration rate (Saft et al., 2015). This shift could likely have led to a reduction in flood hazards during the above-average rainfall events in 2010.

Second, **societal mechanisms are poorly represented in disaster risk analysis and the same holds for their interactions with physical factors**. Research on multi-hazard events, cascading, compound and connected events has made substantial efforts toward an increased understanding of risks derived by the interactions of multiple factors (de Ruiter et al., 2020; Gill et al., 2020; Raymond et al., 2020; Zscheischler et al., 2018). However, these studies tend to ignore societal aspects as they almost exclusively have a natural hazard perspective (Ridder et al., 2020; Zscheischler et al., 2018), or they account only partially for interactions and feedback loops with the societal system (Gill & Malamud, 2017; Raymond et al., 2020).

Third, there is a **lack of in-depth case studies in real-world contexts.** Current multi-risk analyses usually focus on two natural hazards and a specific type of process/interaction (e.g., cascading, concurrent or compounding), often using simulations of synthetic cases (Ciurean et al., 2018). Hence, these analyses are not able to provide accurate multi-risk estimates in real-world contexts. The same holds for the analysis of drought-to-flood events in highly vulnerable contexts, where events develop through the complex interactions of multiple hazards and societal processes, which are currently not included in most simulation models (Brunner et al., 2021; Prudhomme et al., 2011).

Finally, **droughts and floods are studied separately in past and current frameworks for risk analysis.** One of the reasons for their separate analysis is that these two hydrological extremes evolve from different processes,

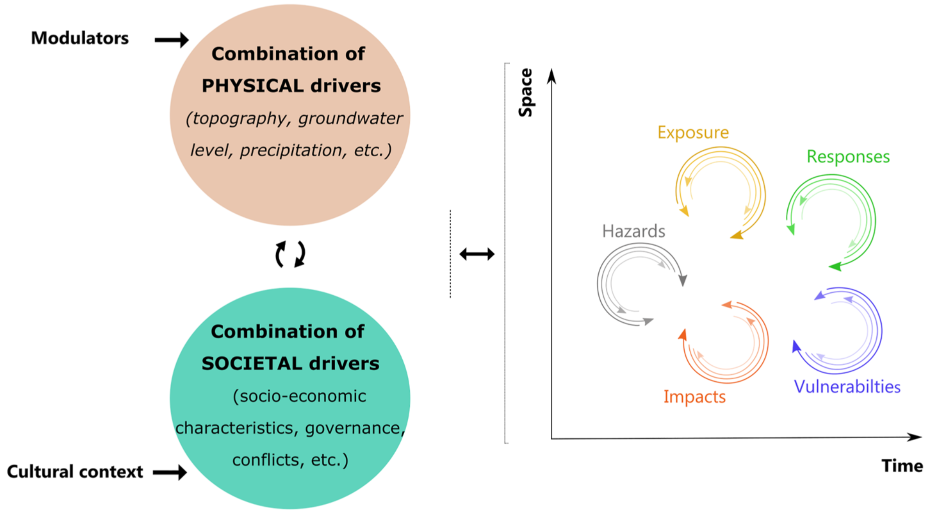

Figure 1. Schematic representation of the interactions between physical and social drivers, risk components (i.e., hazard, exposure, and vulnerability), impacts and societal response over time and space. The risk components can vary over time and space based on the dynamic interactions between physical and societal factors, but also due to the interactions between the risk components themselves and between the risk components, impacts and responses. This dynamic is represented by the circular arrow symbol, while multiple internal arrows represent different hazards, exposure, vulnerability, response and impact types, highlighting their internal interactions. In the diagram, the "response" element refers to both adaptation measures and disaster risk reduction measures. Modulators represent weather patterns that influence or lead to certain physical drivers (e.g., El Niño–Southern Oscillation, Indian Ocean Dipole). The diagram is built upon recent concepts and frameworks of compound (Zscheischler et al., 2020) and connected (Raymond et al., 2020) weather and climate events, and multi-hazard analysis (Gill & Malamud, 2017; Simpson et al., 2021).

have different spatial and temporal scales, and result in different cascading impacts (Blöschl, 2006; Brunner et al., 2021; Kreibich et al., 2019; Skøien et al., 2003; Stahl & Hisdal, 2004). Floods are often fast phenomena occurring in relation to excess rainfall, snowmelt, high soil moisture content and/or high groundwater levels. The effects of these events are commonly limited to one or two catchments. Droughts are slow-onset processes, often occurring in relation to precipitation deficit, high evapotranspiration, and/or over-abstraction. These events might cover larger areas than floods without being limited by the hydrological characteristics of the watershed (Kreibich et al., 2019; Van Loon, 2015). Finally, the impacts of droughts evolve over longer time scales than impacts from floods and different societal sectors are impacted by different drought types. Despite those differences, drought and floods are two extremes of the same hydrological cycle and hence it is important to study them in a joint framework (Brunner et al., 2021; Huntington, 2006), as well as foster an integrated management of their risks (Ward, Blauhut, et al., 2020; Ward, de Ruiter, et al., 2020).

To address these four challenges, we propose a new conceptualization of the interactions between societal and physical systems in disaster risk analysis (Figure 1). In this conceptualization, societal and physical factors can influence all risk components, and it includes feedback loops between risk components, impacts and responses. In addition, dynamic changes in hazards, exposure, vulnerability and impacts over time and space are considered. Through this increased degree of freedom, we can represent different multi-risk interactions (e.g., cascading, compounding).

3. Case Studies

The proposed conceptualization was used to analyze the 2017–2018 drought-to-flood related humanitarian crises in Kenya and Ethiopia. Droughts and floods are not new phenomena in these two countries (Ayugi et al., 2020), but in recent years a rapid transition between these two extremes and their increased frequency and magnitude have been experienced (Huho & Kosonei, 2014; Figures 2a and 2b). Although flood events in the last 3–5 years have been substantial in terms of their impacts on both countries, the number of people affected by droughts is higher: about 10 times higher than the number of people affected by floods (Figures 2a and 2b). Analyzing

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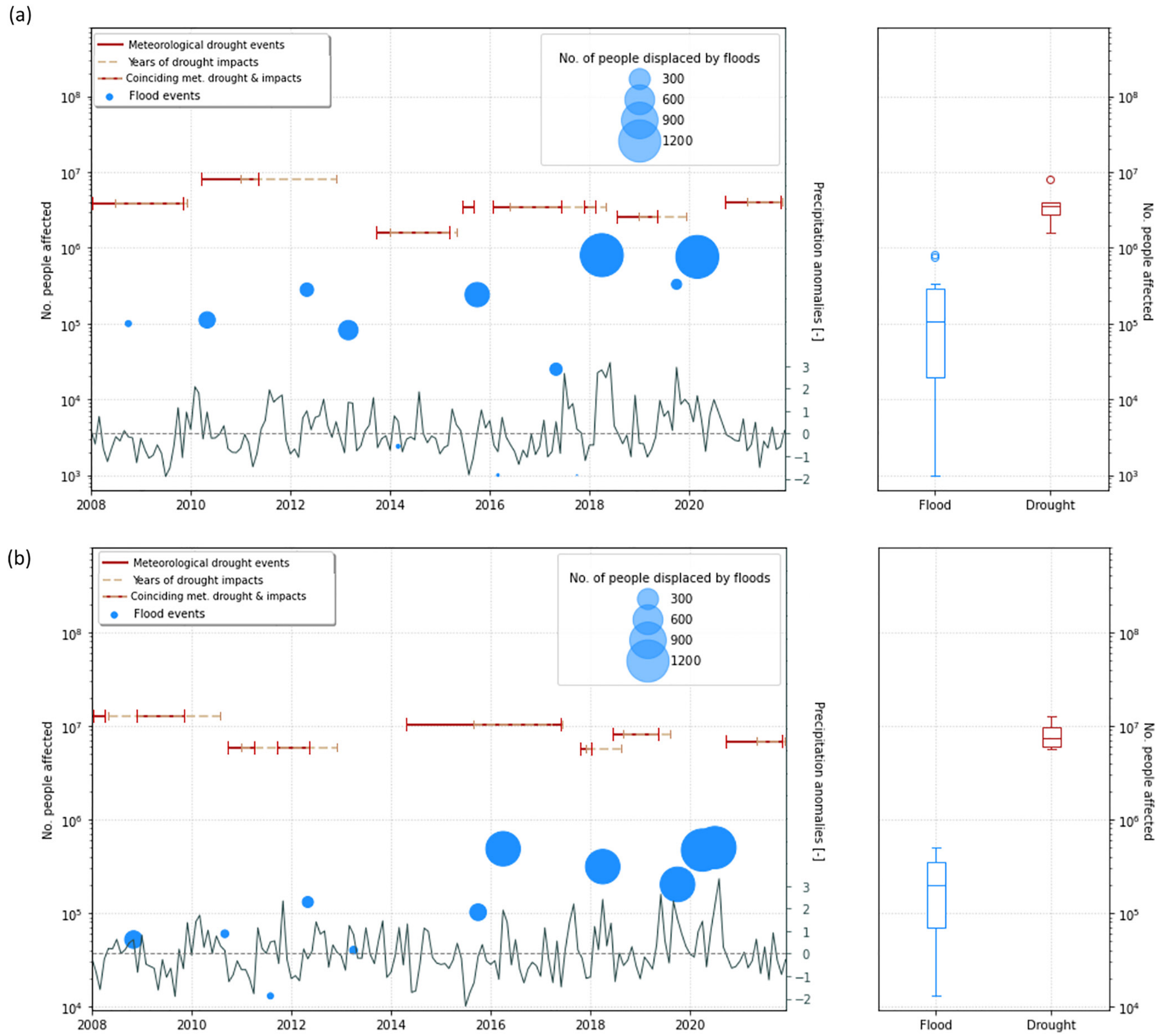

Figure 2. Drought and flood events and impact timeline for Kenya (a) and Ethiopia (b). The time series of the monthly anomaly standardized precipitation index (dark green lines at the bottom of the graphs) were computed from Climate Hazards group Infrared Precipitation with Stations data. Specifically, we computed the deviations of the monthly precipitation from the long-term monthly average (1990–2021), which was then standardized by dividing by the standard deviation of monthly rainfall; its values are shown on the right *y*-axis. The dotted line ("Years of drought impacts") refers to the duration of the drought impacts retrieved from the EM-DAT data set. The continuous red line ("Meteorological drought events") refers to the duration of meteorological drought events, estimated through the anomaly standardized precipitation index (drought events identified according to index values below −0.1, 2-month pooling and at least 3 months of consecutive anomaly). The number of affected people for drought and flood events and displaced people for flood events were extracted from the EM-DAT and DesInventar datasets. The number of people affected by drought and floods is shown on the left *y*-axis while the number of people displaced by floods is shown according to different circles diameters.

these hazards separately, drought remains the most prevalent hazard in terms of people affected and fatalities (CRED, 2019).

The abrupt transitions from drought to flood experienced in Ethiopia and Kenya in the last 5 years underscore the need to understand societal and physical processes characterizing these drought-to-flood events. Accordingly, we analyzed the years 2017–2018, in which a severe drought (Funk et al., 2019; Philip et al., 2018; Uhe et al., 2018) was followed by widespread floods (Kilavi et al., 2018; Njogu, 2021). Simultaneously, both countries faced crop pest infestations (De Groote et al., 2020; Kumela et al., 2019) and socio-political unrest (Awobamise et al., 2020; D'Arcy & Nistotskaya, 2019; Lavers, 2018). The burden imposed by the two hydroclimatic extremes combined

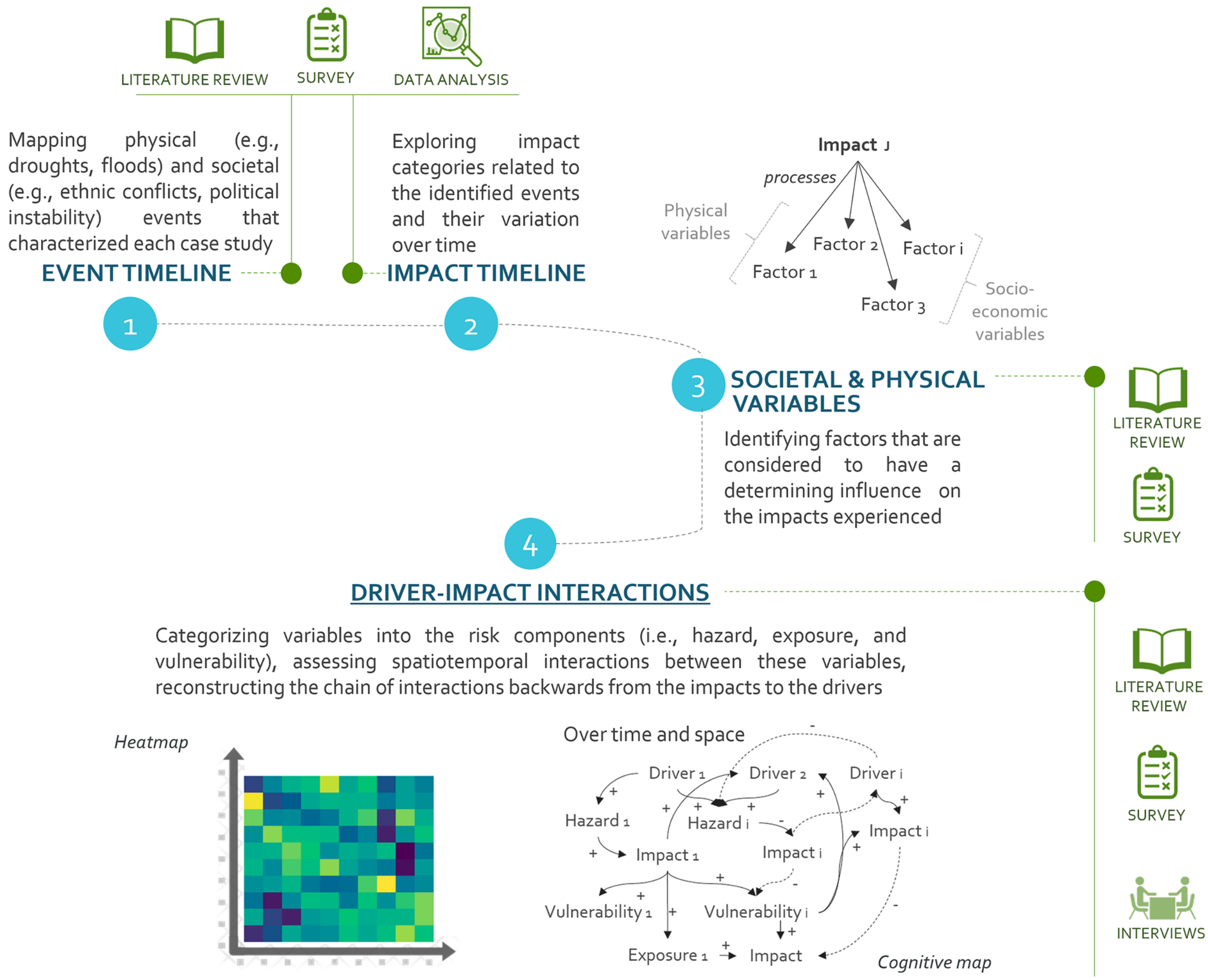

Figure 3. Stepwise, bottom-up approach used in this study to investigate interactions between societal and physical variables during multi-risk events. The green colored icons represent the methods used in each step.

with the fall armyworm infestation, government elections and ethnic conflicts led to four million people under food insecurity in Kenya (FEWS NET, 2018) and eight million in Ethiopia (FEWS NET, 2019). Yet, there is a poor understanding of the main physical and societal drivers of the crisis, the interaction of these multiple events and the resulting cascading impacts.

4. Data and Methods

In this study, a range of qualitative and semi-quantitative methods was used, within a stepwise, bottom-up approach. This approach begins with identifying the impacts, then the factors that could have led to those impacts, and finally we reconstructed the pathways linking the impacts to the drivers. Further, the approach allowed us to investigate interactions and feedback loops between societal and physical factors, risk components, impacts and responses, over time and space, as illustrated in the conceptual diagram presented in Figure 1.

As shown in Figure 3, our approach consists of four main steps: (a) develop the event timeline; (b) develop the impact timeline; (c) identify societal and physical variables; (d) map driver-impact interactions. These methods were used iteratively, which allowed us to refine the methods according to the progressive acquisition of knowledge and data. We brought together the diverse strands of evidence and graphically summarized them in the form of heatmaps and cognitive maps. The heatmaps allowed us to represent interactions between variables and impacts, while the cognitive maps allowed us to represent the multiple pathways from drivers to impacts across time and space. In Section 4.1 we explain the data and the methods used to collect different evidence types. We outline limitations associated with these methods in Section 4.2.

4.1. Methods

4.1.1. Literature Review

A comprehensive review of the literature was undertaken in order to identify the events, the impacts experienced, and the societal and physical variables that may have led to those impacts during the years 2017–2018 in Kenya and Ethiopia. Our review procedure followed the guiding principle proposed by Boaz et al. (2002) and applied by Gill and Malamud (2014, 2017) (Table S2 in Supporting Information S1). For the delineation of a preliminary event timeline, a backward snowballing method was applied (Wohlin, 2014). A start set of literature was identified through a Boolean search performed on 10 November 2020 and based on the keywords: ("humanitarian" *or* "crisis") *and* ("Ethiopia" *or* "Kenya") *and* ("2017" *or* "2018") (see Table S3 in Supporting Information S1 for more details on the search strings used). These keywords were used in large web databases for peer-reviewed articles (Google Scholar and Web of Science), and in the Google online search engine to identify relevant gray literature (e.g., newspapers). No end time constraints were used; however only articles published after 1 January 2016 were considered. For the identified references, we scanned their titles and their abstracts to determine their relevance in relation to the first objective of our review: the identification of physical (e.g., drought) and socio-economic (e.g., government elections) events that characterized the years 2017–2018 in Kenya and Ethiopia (question one of Table S2 in Supporting Information S1). We stopped the literature search at the second iteration, yielding a total of 12 references for Kenya and 22 references for Ethiopia. This process helped us to develop a preliminary timeline of events, which we further investigated through time series analysis and an online survey (Sections 4.1.2 and 4.1.3).

Subsequently, we prepared a preliminary list of 34 expected impacts associated with the identified events. The list was first developed from the literature review (for droughts: Stahl et al. (2016), for floods: Adhikari et al. (2010), for conflict: Solomon et al. (2018)), and then discussed with four humanitarian experts from international, non-governmental and academic institutions. Impacts in the preliminary list were used as keywords for a new Boolean search on Google search engine, with the aim of identifying relevant literature. For example, each keyword from the list (e.g., "deterioration of health conditions") was used alongside "Kenya" *or* "Ethiopia" *and* "2017" *or* "2018" (see Tables S3 and S4 in Supporting Information S1 for more details on the search strings used). The approach resulted in the identification of 63 peer-reviewed and gray literature sources for Kenya and 102 for Ethiopia. Relevant literature included journal articles, technical reports, newspaper articles, NGO disaster situation reports, and government and NGO bulletins. For Kenya, we also used the Quarterly Gross Domestic Product reports issued by the Kenya National Bureau of Statistics. The reports provide an overview of the economic conditions of key sectors (e.g., agriculture, hydroelectric power generation, etc.) and include analyses of the causes of economic growth or recessions. Unfortunately, such data were not available for Ethiopia.

For each cited impact, we recorded information on their spatial and temporal occurrence, interaction types and variables, through close-reading analysis (Schur, 1998). For the identification of interaction types (increasing, decreasing and feedback loops) and variables (definition in Table S1 in Supporting Information S1), we performed another Boolean search using keyword verbs that suggest a correlation between impacts and societal/physical variables (similar to Gill et al., 2020). Accordingly, we used the following nine keywords: "trigger", "provoke", "generate", "cause", "increase", "worsen", "decrease", "reduce" and "alleviate." The approach helped us to systematically quantify the frequency with which a certain correlation was mentioned, and enabled us to understand the direction of these correlations (positive or negative). Building upon earlier work (Gill & Malamud, 2014, 2017), we synthetized and presented the findings in a matrix form.

4.1.2. Time Series Data Analysis

For the definition of the extreme hydrological events and impacts, we also carried out time series analysis of rainfall and socio-economic data (Table S5 in Supporting Information S1). We computed standardized rainfall anomalies from Climate Hazards group Infrared Precipitation with Stations (CHIRPS) precipitation data aggregated at national and regional/county level. Further, through open source and national databases, we collected time series data on crop and livestock production, gross domestic product (GDP), population affected by food insecurity, food prices, number of incidences, number of displaced people, and registered disease outbreaks. We selected these variables based on information on events and impacts gathered from the literature review and data availability. The spatial and temporal scale of these data vary from county or regional level to national level and from monthly to yearly.

The time window of analysis was selected in accordance with the literature review and the analysis of rainfall time series, which revealed that dry spell conditions developed before 2017. To cover these events, we extended the analysis of the time series to 2016–2018 in Kenya and 2015–2018 in Ethiopia.

4.1.3. Stakeholder Online Survey

A web-based survey (https://doi.org/10.5281/zenodo.5866460) was prepared in order to gain insights on the events, impacts and interaction types that marked the 2017–2018 humanitarian crises in Kenya and Ethiopia. The questionnaire was pre-tested by four academics. The survey was then shared with 150 Kenyan stakeholders and 80 Ethiopian stakeholders identified through snowball sampling. During this process, the initial participants were identified through professional contacts, our previous literature review, and a further Google search. The initial sample group was asked to indicate other relevant participants, resulting in a chain sampling of potential participants. The process led to the identification of a range of experts in disaster risk reduction/management and humanitarian response. A total of 24 Kenyan and 16 Ethiopian stakeholders participated in the online survey (16% and 20% of those invited, respectively). These included professionals of different levels of seniority, who work in the fields of disaster risk reduction/management, water management, and economics in national/international agencies, NGOs, and universities. About 50% and 60% (for Kenya and Ethiopia, respectively) of these professionals work at the national level, 30% work at the local level, and the remainder at the regional level. The survey was informed by the preliminary literature review and addresses each step of the methodological approach (Section 4), through four dedicated sections, in which a series of multiple choice and open-ended questions were used.

Specifically, the survey addressed: (a) events that occurred in the years 2017–2018; (b) impacts experienced; (c) drivers of the impacts experienced; (d) interaction between drivers and impacts. In the first section of the survey, we asked the participants to recall the main events that characterized the years 2017–2018 in their respective country/region. As the task requires a memory effort, we have prepared video collages of drought and flood news from the main Kenyan and Ethiopian media channels respectively, to help respondents recall the years under analysis. Then, we asked respondents to validate the preliminary event timeline obtained from the literature review and to add any relevant events in case these were missing from the timeline.

In the second section of the survey, we investigated the impacts felt in the years 2017–2018. We asked respondents to select (or add any other) impacts that they remember to have occurred in their country during the period under analysis. Then, we asked them to identify the four major impacts among them and to classify them from one (highest) to four (lowest) according to their magnitude and resources needed to provide adequate responses. With a similar approach, in the third section of the survey, we asked respondents to: (a) identify potential drivers of the impacts experienced, (b) select relevant drivers from a prepared list, (c) identify and rate four major drivers according to their influence on the impacts experienced, and (d) briefly write how the identified drivers led to the experienced impacts.

In the last section, we explored the interactions and feedbacks between drivers and impacts. In particular, we asked respondents to fill in an empty driver/impact matrix in which the impacts and drivers, on the x and y axes, respectively, were the ones they identified as the most relevant in the previous sections. Participants could define the type of interaction, for each driver/impact combination, according to the following options: 0 (neutral), +1 (slightly amplified), +2 (widely amplified), −1 (slightly reduced), −2 (greatly reduced).

4.1.4. Semi-Structured Stakeholder Interview

Additional evidence on impacts, drivers and their interactions was gathered through semi-structured interviews. We selected participants according to their experience and relevance to the research questions, in agreement with MacDougall and Fudge (2001). We interviewed seven Kenyan and four Ethiopian professionals following an expert sampling technique. The interviewees work for the water management sector, hydro-meteorological services, and disaster risk management/reduction in international research centers, NGOs, national government, and private sectors. The persons interviewed were identified from those who participated in the online survey.

This facilitated the elicitation of event interactions, since these participants had recently reviewed the events in the period under analysis.

Interviews lasted from 30 to 90 min and followed a semi-structured approach (Bryman, 2012). A clear interview schedule tailored to the interview context was prepared. One of the aims of the interview schedule was to ensure that some questions were asked in the same way to each respondent. All interviewees were recorded if they authorized us to do so. Each interview was then transcribed and summarized. Data collection and storage followed the Code of Ethics of Vrije Universiteit Amsterdam (https://vu.nl/en/employee/social-sciences-getting-started/research-ethics-review-fss). Before the interview, we drew a preliminary cognitive map representing the pathways from impacts to drivers and the interrelationships between risk components based on the results from the literature review and the online surveys. We rearranged processes and events from the literature review and the online survey in a hierarchical structure to represent dependencies. These allowed us to reconstruct the chain of events from the impacts to their primary drivers. This map was then reviewed by each participant, discussing dominant or missing processes. Participants naturally converged in the group discussions.

4.2. Limitation of the Methods

The methods described in Section 4.1 are each associated with limitations and uncertainties.

Information Accuracy: It might be difficult to verify the reliability of blended sources of gray literature (Gill et al., 2020), particularly when these include media articles, NGOs and government bulletins. The same is the case with interviews and online surveys where stakeholders bring a personal perspective of the events under analysis and their interrelationships. To overcome these limitations, we assessed authenticity by comparing information obtained through the literature review with that provided by stakeholder interviews, online surveys, and time series data analysis. By integrating multiple types of evidence, we aimed to reduce the uncertainties and limitations of the methods used.

Cognitive biases: Biases related to a systematic error in thinking might occur during stakeholder interviews and online surveys. The way stakeholders remembered the period under analysis might be biased by individual motivations, personal emotions and experiences. To overcome these limitations and improve the quality of the information elicited, Browne and Rogich (2001) and Pitts and Browne (2004) suggest the use of context-dependent questions. Accordingly, our questions were context specific, addressing precise events of the period under analysis. Further, in the online survey we used visual information on the drought and flood events to enhance the episodic memory process. We recognize these visuals introduced biases in relation to the memory of drought and flood events, but we accepted this bias because the visual information also facilitated a fine-grained level of remembering.

Uncertainties and biases in the time series data: Time series data has uncertainties related to systematic errors in the collection process. Uncertainties can also arise from the spatial and temporal aggregation process used. In order to reduce these biases, we crosschecked the same variables from different data sources (when available) to verify that the order of magnitude is similar. Data at highest spatial and temporal resolution were preferred. Another uncertainty was brought about by the selection process of the variables used for the data analysis, which was limited by the availability of the data. Hence, other socio-economic data and finer spatial and temporal resolutions could have further reduced the bias in the analysis.

Hypothetical Conditions: Reviewing the humanitarian bulletins, we noted that some of the impacts and interrelations mentioned refer to a hypothetical context that could occur if no effective response was provided. In order to distinguish between real and hypothetical conditions, we screened each document with particular attention to the sentences surrounding the identified keywords and the verb tenses used.

Information Omission: Semi-structured interviews and online surveys have a predefined format, discussion points, and options. This increases the likelihood of missing important information (Gill et al., 2020). To overcome this limitation, we started each section of the online-survey with open-end questions so as not influence respondents by limiting their response to the options offered in the multiple-choice questions. For the latter, we provided the possibility to insert any other answer not listed among the options. In the semi-structured interviews, we reserved 15 min at the end of the interview for any points that the participants believed may be relevant to discuss. Finally, the pre-selection of keywords for the identification of impacts and drivers from the literature review and online survey could represent a further limitation of this study. One way to reduce this bias in literature review and online survey analysis would have been the identification of category keywords from the set of documents identified in the preliminary event research (see the work of Madruga De Brito et al., 2020). However, in our study we did not want to limit the identification of the impacts to the events, in order not to constrain the type of factors, events and interactions that could have played a role in the years analyzed.

Sampling Bias: Sample selection bias in the literature review could lead to a partial representation of the system under analysis. In our study, for instance, newspapers may not be able to grasp the range of perspectives of marginalized communities. To address this bias, we based our literature review analysis on different types of literature such as NGO bulletins, government reports, newspapers and peer-reviewed articles with the aim of capturing different perspectives.

Sample Size: Sample size is important in both data analysis and qualitative research to reduce possible error. Due to the nature of our event-based study, we focused on a short time frame (three to 4 years). This limited the type of data analysis methods and their use in the study. For instance, statistical analysis to identify dependencies and correlations could not be applied. Our data analysis, therefore, primarily aimed at complementing information obtained from the literature review and stakeholder online survey to provide insight into anomalies. This was done by comparing the data of the analyzed time period with data of the previous 20 years. Further, despite the small sample size in the stakeholder interviews and the online survey, participants had different backgrounds and fields of work, capturing different narratives and perspectives of the interactions that characterized the period under analysis.

5. Results

In Sections 5.1 and 5.2, we present the results for Kenya and Ethiopia respectively, addressing each step of the approach described in Section 4.

5.1. Kenya

5.1.1. Event Timeline

In 2016–2018, Kenya experienced a succession of drought and floods and other exceptional physical and societal events (Figure S1 in Supporting Information S1). In particular, crop pest infestation and prolonged government elections were two other major events reported in the literature, online survey, and stakeholder interviews.

Rainfall deficits during the "short rainy season" (October-December) of 2016 were perceived as the main cause of drought conditions in the northwest and southeast of Kenya. However, the late onset, poor distribution, and early cessation of the 2016 short rains alone do not explain the drought condition experienced in late 2016. In the southeast, the 2016 short rains compounded with a low soil moisture precondition resulted from rainfall deficit during the "long rainy season" of the same year (March-May 2016).

On 10 February 2017, the government declared a national drought emergency, which was further exacerbated by another rainfall deficit over the long rainy season of 2017 (March–May). The drought conditions lasted until May 2018, despite several extreme wet events occurring in between. Only the heavy rainfall during the 2018 long rains interrupted the drought cycle. This rainfall event also led to flash floods and widespread riverine floods, landslides, and dam spillage and failure. The complexity of the precipitation event meant that forecast lead times were shorter. As such, the long lead seasonal climate forecasts did not provide enough indication that exceptional rain could occur.

Coinciding with the drought, many counties in Kenya had an infestation of fall armyworm. The pest was first detected in Kenya in March 2017 and was held responsible, along with the drought, for the decrease in the production of maize and sorghum (the crops preferred by the parasite). The worms also targeted wheat and barley crops, which grow mainly in the western counties together with maize. By July 2017, it had infested 40% of farms, affecting around 200,000 ha of land in the main maize-producing counties. The infestation seemed to have stopped at the beginning of 2018 with a resurgence only in early 2019. The year 2017 also had government elections, which took place first in August 2017 and then again in October 2017 since the Supreme Court nullified

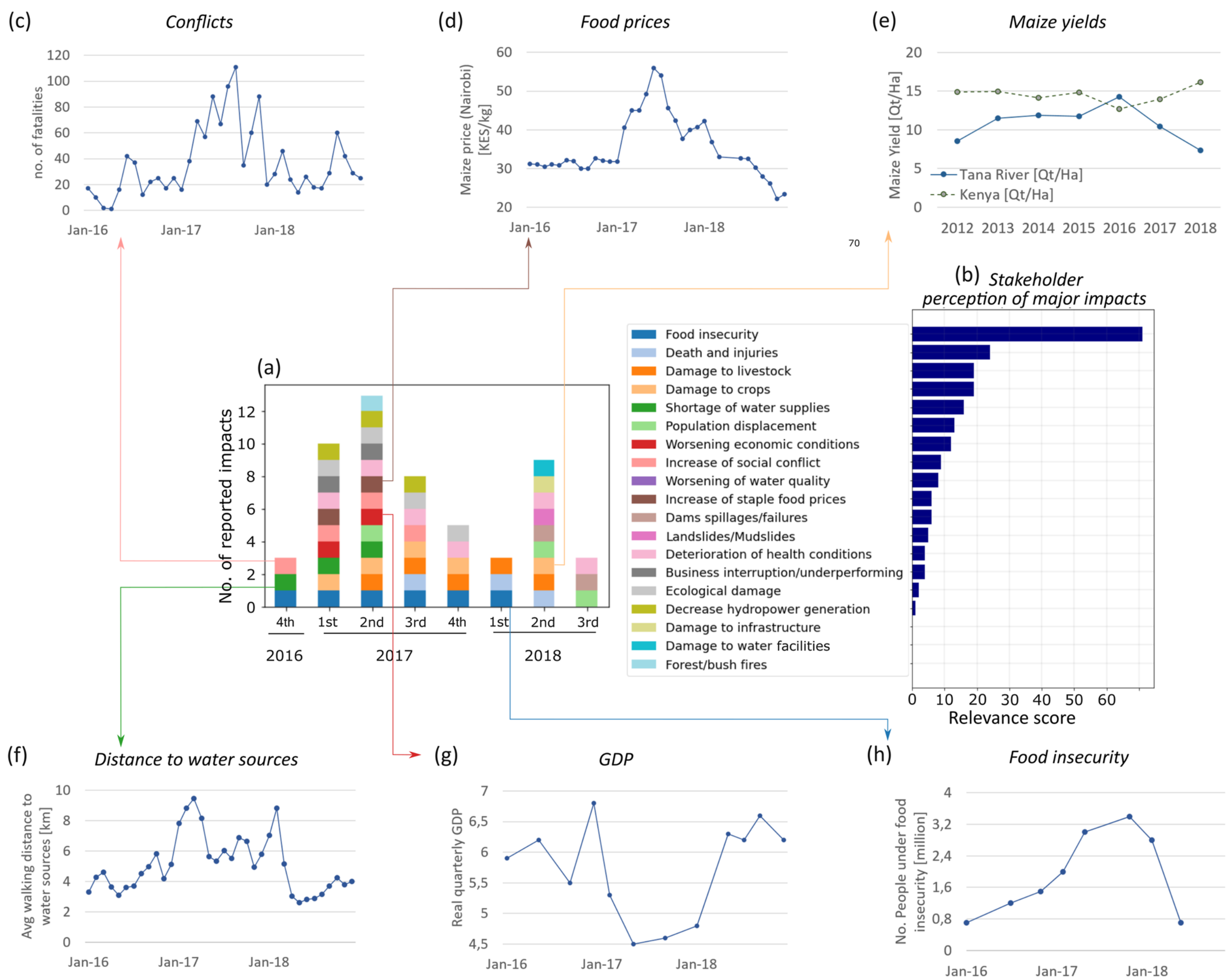

Figure 4. Kenya impact analysis over time, with: (a) quarterly impacts reported in the reviewed literature; (b) their perceived damage in terms of magnitude and needed resources for effective responses according to the online survey, time series data of: (c) number of fatalities, (d) nominal maize price in Nairobi, (e) maize yield in Tana River and Kenya, (f) average walking distance to water sources, (g) real quarterly gross domestic product (GDP), (h) number of people under food insecurity.

the results of the first election. The electoral campaign was one of the most expensive, and its period was marked by violence and unrest, which further increased vulnerability of affected communities.

5.1.2. Impact Timeline

The quarterly distributions of reported impact categories (Figure 4a) illustrate the diversity of the impacts experienced throughout the analyzed period as well as dynamic changes in vulnerability. Food insecurity, which was reported throughout almost the entire analysis period (Figure 4a), has also been perceived as the major impact (Figure 4b). From December 2017, food insecurity values began to decrease (Figure 4h), with a more marked decline from March 2018 onwards. This coincided with a decrease in the average walking distance to water sources (Figure 4f) and an increase in national maize yields (Figure 4e). In the same period, on the other hand, the impacts on damage to infrastructures and on water facilities (such as boreholes) and landslide/mudslide events triggered by heavy rainfall appear prominently (Figure 4a). Yet, these impacts did not affect all parts of Kenya equally. Reports on damage to water supply systems mentioned that this mostly occurred in semi-arid regions and close to riverbanks, while reports on landslide and mudslide events referred mainly to areas in central-western counties where topography is highly variable.

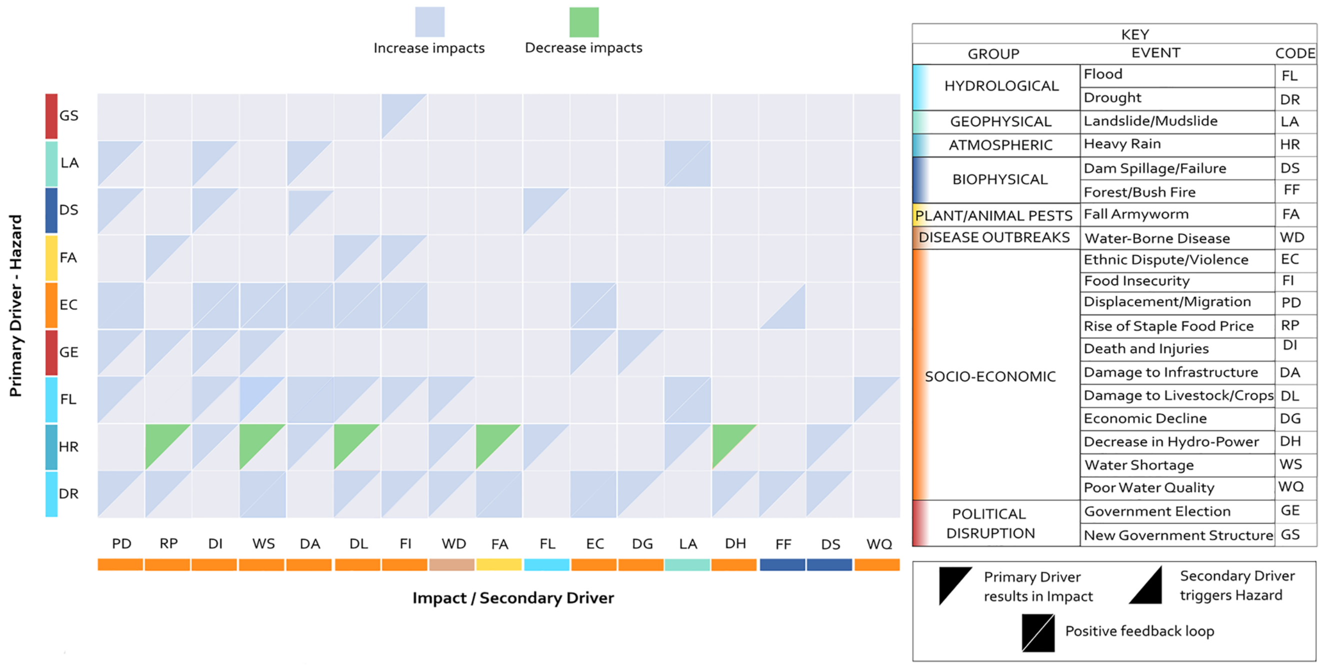

Figure 5. Heatmap summarizing the predominant interactions between physical/societal variables and impacts at national level according to the different sources of evidence explored. Negative interactions (blue) increase the impacts while positive interactions (green) decrease the impacts. Shading in the upper-left triangle indicates that the variable is either increasing (blue) or decreasing (green) the relative impact. Shading in the lower-right triangle indicates that the driver/impact can increase the probability of a hazard. Shading in the whole cell indicates positive feedback loops and hence reinforcing mechanisms that further increase the impacts and the drivers. Event classification modified from (Gill & Malamud, 2014).

With a substantial gap, deaths/injuries and damage to livestock/crops follow food insecurity as major impacts perceived by the stakeholders (Figure 4b). Damage to crops was reported in the first quarter of 2017 (Figure 4a) and coincided with a decrease in national crop yields in late 2016 (Figure 4e). In the same period, staple food prices rose markedly (Figure 4d), while GDP growth decreased (Figure 4g). In the second quarter of 2018, however, the damage to crops (Figure 4a) was not reflected clearly in a decrease in national agricultural production (Figure 4d), which instead shows a full recovery in that year. Crop losses were mainly reported in the arid and semi-arid Kenyan regions, which present a minimum contribution to the annual average national production. Finally, an increase in social conflicts was recorded from the fourth quarter of 2016 until the third quarter of 2017, with the number of incidences increasing from June 2017, close to the election period.

5.1.3. Societal and Physical Variables

Through the systemic literature review, for the 34 impacts investigated, we identified the following eight societal and physical variables: drought, flood, heavy rain, landslides, fall armyworm, government elections, ethnic conflicts, and dam spillage/failure. Although the flood in 2018 was triggered by heavy rainfall, we analyzed both floods and heavy rain as potential drivers because different interaction types emerge. Further, the literature review shows that floods, landslides and dam spillage are both driving factors (of crop losses, damages to infrastructure, etc.) and impacts (as resulting from other events such as heavy rains, drought, etc.). Therefore, we explored those events as both drivers and impacts with the aim of considering cascading processes. In the online survey, 83% of respondents indicated drought as one of the drivers for the events experienced in Kenya between 2017 and 2018. This was followed by flood, government response and conflict (mentioned by around 75%, 45% and 41% of respondents, respectively). In contrast, when we asked to indicate which of the drivers had a major influence on the impacts experienced, drought and flood stood out, followed by conflicts.

5.1.4. Driver-Impact Interactions: Heatmaps

The interactions between societal/physical variables and impacts were recorded in a matrix and summarized graphically in the form of a heatmap (Figure 5). In particular, the figure summarizes the predominant drivers/impacts interactions at national level according to the different sources of evidence explored (heatmap from the literature review process in Figure S2 in Supporting Information S1 and heatmap from the online survey in Figure S3 in Supporting Information S1). The analysis revealed the occurrence of 72 interactions in the years under analysis. Among the identified interactions, we notice that the occurrence of one event influenced (or caused) others. This means that in some cases a driver increased a certain impact (i.e., negative interaction), while it supported the mitigation of other(s) (i.e., a positive interaction). For instance, *Heavy rain* increased *Flood*, but also decreased *Water shortage*. At the same time, we can also observe that, in some cases, an impact became a driver of a subsequent event. For instance, *Drought* led to *Migration/Displacement* which in turn exacerbated *Ethnic dispute/violence* (Figure 5).

Analyzing the heatmap (Figure 5), we can observe that *Drought*, *Floods* and *Ethnic dispute/violence* present the largest number of negative interactions with the investigated impacts (each related to 12, 10, and eight impacts, respectively). *Heavy Rain* also has a large number of interactions with the identified impacts (11), but compared to the other drivers it has both negative and positive interactions. In detail, *Heavy rain* was related to the increase of *Floods*, *Landslides* and *Dam spillage/failure*. At the same time, *Heavy rain* (driver) was also related to a decrease in *Water shortage* (impact), increase in *Hydropower* production (impact), reduced *Damage to livestock/crops* (impact) and reduced *Fall armyworm* infestation (impact). Further, *Ethnic violence* (impact) were mainly driven by the *Government elections* (driver) and *Drought* (driver).

5.2. Ethiopia

5.2.1. Event Timeline

In 2017–2018, Ethiopia experienced droughts, widespread riverine floods and flash floods, fall armyworm infestation, political power change, and two ethnic conflicts (Figure S4 in Supporting Information S1). To capture possible drivers from before the period under analysis, we explored rainfall anomalies starting from 2015. The analysis shows two periods of meteorological drought: one that occurred in 2015–2017 (which mainly affected the western regions) and another that occurred in 2016–2017 (which mainly affected the eastern regions). The first drought was caused by subsequent below-normal rainfall in 2015, 2016, and early 2017. The drought conditions ended with above-normal rainfall rates during Kiremt summer season (June–September; spatio-temporal distribution of the rainy seasons in Ethiopia is shown in Figure S5 in Supporting Information S1) in 2017, which also resulted in riverine floods and flash floods in Afar, Amhara and the Oromia regions. On the other hand, the normal rainfall of Deyr (October–December) in 2017 was not sufficient to reverse the effects of drought conditions in the eastern regions. Only the heavy rains of the late Belg/Gu season (February–May) of 2018 helped to break the drought cycle in the eastern regions. The extremely wet event also led to widespread flooding and landslides in the regions of Somali and Eastern Oromia. Drought conditions in 2017 compounded with the fall armyworm infestation, threatening crop production. The crop pest was detected in February 2017 and quickly began spreading to several maize plantations in southern Ethiopia.

Adding to these climatic shocks and biological hazards, widespread anti-government protests broke out in Oromia and Amhara region in July 2016, followed by an escalation of civil unrest on the Somali-Oromia border in September 2017 through February 2018. Subsequently, intercommunal violence occurred along the borders of the Gedeo (SNNPR) and West Guji (Oromia region) areas in April 2018. Tensions between the two groups have been centered on land, border demarcation, and ethnic minority rights and lasted until June 2018.

5.2.2. Impact Timeline

The quarterly distribution of the impact categories from the literature review has some agreements with the stakeholder impact perception. Food insecurity is reported for almost the entire period analyzed (Figure 6a) and was also perceived as being one of the major impacts experienced (Figure 6b). From the end of 2015 until the end of 2016, the number of food-insecure people increased to over nine million (Figure 6f). At the same time, agricultural production declined (Figure 6e) and GDP growth slowed by 1% (Figure 6g). Another increase in food insecurity was recorded in early 2017 with around eight million people registered in conditions of food insecurity (a value that remained constant throughout 2017 and 2018; Figure 6f). This increase in food insecurity coincided with a sharp rise in staple food prices, driven by the poor yield of the Belg harvest (harvested period: June–July) and concerns over the fall armyworm infestation on the Meher harvest (harvested period: October–December). However, thanks to the abundant Meher harvest, prices began to decline in most markets from August 2017 (Figure 6d). This decrease in staple food price did not occur in areas affected by conflicts (e.g., Somali and east

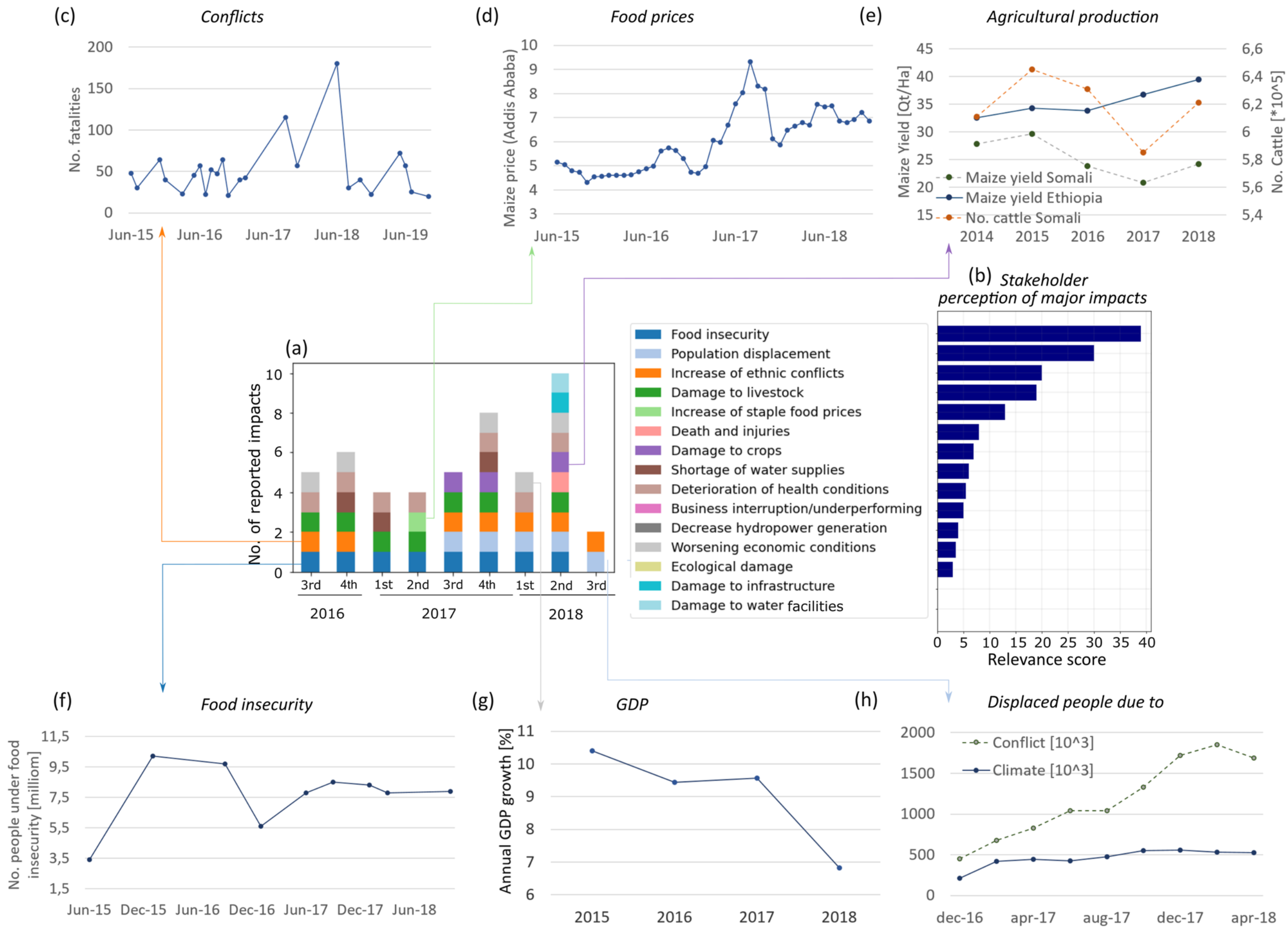

Figure 6. Ethiopia impact analysis over time: with (a) quarterly impacts reported in the reviewed literature, (b) their perceived damage in terms of magnitude and needed resources for effective responses according to the online survey, time series data of: (c) number of fatalities, (d) nominal maize price in Addis Ababa, (e) maize yield in Somali and Ethiopia, (f) number of people under food insecurity, (g) annual gross domestic product (GDP) growth, (h) number of people displaced.

Oromia; Figure 6c), where the series of clashes disrupted the normal flow of commodities from surplus areas to deficit markets. Additionally, in the same areas, the drought conditions had repercussions on smallholder farmers and pastoralists (Figure 6e), further contributing to their food insecurity. Prices began to decline in whole regions only from early 2018, although they remained 20%–40% above their respective monthly average prices (Figure 6d). After food insecurity, population displacement was perceived as the second largest impact. The highest numbers of displaced persons (Figure 6h) occurred at the same time as the increase in the number of fatalities (Figure 6c), due to the Somali-Oromia and Gedeo-West Guji conflicts. In the same period, GDP growth showed a decline of around 3%. Rising conflict, food insecurity and slowing GDP growth between late 2017 and mid-2018 capture also a growing vulnerability to disasters on the part of both communities and the government.

5.2.3. Societal and Physical Variables

Through the systematic literature review, for the 34 impacts investigated we identified the following eight variables: drought, flood, heavy rain, landslides, fall armyworm, political instability, ethnic conflicts, economic decline, and population displacement. Like in Kenya, heavy rains and floods show different types of interactions with other social and physical variables. Furthermore, economic decline and population displacement were found in the literature review as both impacts and drivers of subsequent events. In the online survey, conflict was identified as a driving factor of the experienced impacts, with a broad consensus among respondents. This was followed by political unrest, drought and floods (indicated by approximately 75%–70% of respondents). On the other hand, when we asked to indicate which of the drivers had a major influence on the impacts experienced, conflict, drought and political disruption stood out.

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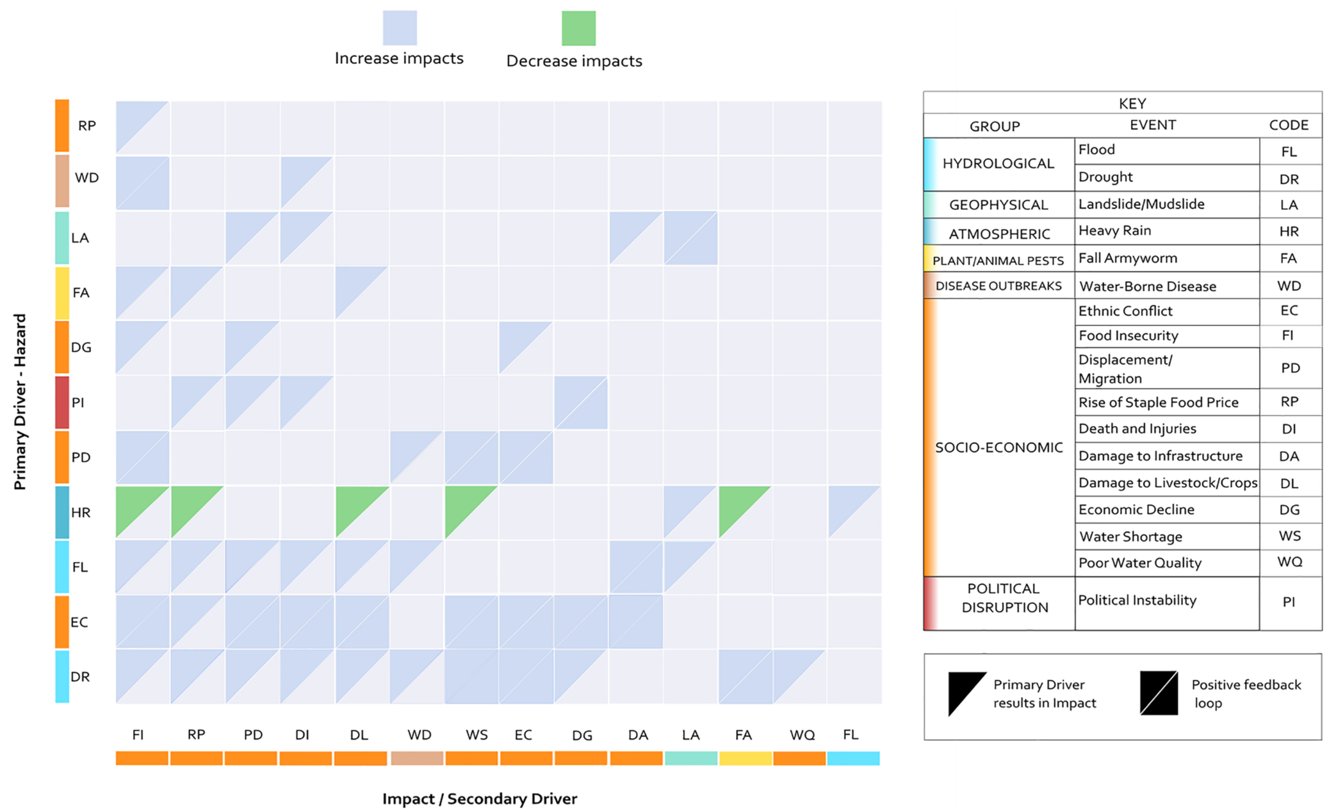

Figure 7. Heatmap summarizing the predominant interactions between physical/societal variables and impacts, predominant in the arid and semi-arid regions of Eastern Ethiopia, according to the different sources of evidence explored. Negative interactions (blue) increase the impacts while positive interactions (green) decrease the impacts. Shading in the upper-left triangle indicates that the driver is either increasing (blue) or decreasing (green) the relative impact. Shading in the whole cell indicate positive feedback loops and hence reinforcing mechanisms that further increase the impacts and the drivers. Event classification modified from (Gill & Malamud, 2014).

5.2.4. Driver-Impact Interactions: Heatmaps

Bringing the diverse evidence types together (Figures S6 and S7 in Supporting Information S1), we identified 74 interactions during the years under analysis (Figure 7). *Drought*, *Conflicts/Violence* and *Floods* present the largest number of negative interactions (increasing impacts) with the investigated impacts, with 11, nine and eight related impacts respectively. *Heavy rain* also shows a large number of interactions with impacts (seven), but most of these interactions are positive, hence resulting in a decrease of certain impacts such as *Damage to livestock/crops* and *Water shortage*. Compared to Kenya, these positive interactions were less marked and occurred over a longer period (around 4–6 months). Other interesting interactions highlighted in the heatmap are those related to *Population displacement*. According to our analysis, *Population displacement/Migration* (impact) was driven by *Drought*, *Ethnic conflicts*, *Floods*, *Landslides*, *Political instability* and *Economic decline* (drivers). At the same time, *Population displacement* (driver) was associated to increase in *Food insecurity*, *Water shortage*, *Ethnic conflicts* and *Water-borne diseases* (impacts).

6. Discussion

Disentangling trends in hazards, exposure, vulnerabilities and impacts, as well as understanding their spatial-temporal interactions, is essential for assessing the risk of humanitarian disasters related to drought-to-flood events. Acquiring this information and knowledge in highly vulnerable contexts can be challenging given the limited availability of data and their reliability. As shown in this study, the integrated use of different evidence types helps overcome the lack of data, while providing broader perspectives on socio-hydrological interactions and their space-time variations. To the best of the authors' knowledge, this is the first study proposing the integration of qualitative and semi-quantitative methods framed in a bottom-up approach to identify interactions between societal and physical factors and risk components in real-world, multi-hazard events. This contrasts with many existing studies on multi-hazard events that focus on a single type of interaction, are based either on a quantitative or a qualitative approach, or do not take into account the spatial-temporal variations of the risk components.

Results from the case studies highlight that **drought and flood events did not act in isolation but compounded with the Ethiopian and Kenyan vulnerable context**, exacerbating the impacts. For example, the combination of drought, ethnic conflict and displacement/migration led to a number of mutually reinforcing interactions (Figures S8 and S9 in Supporting Information S1). Drought affected the migration patterns of pastoralists, exacerbating resource-based conflict and inter-municipal competition for land. This resulted in increased violence and insecurity, hindering the access of humanitarian aid to drought-affected communities. The impacts of floods were also exacerbated by the absence of a specific authority or institutional framework for flood response in arid and semi-arid regions, as the primary focus was on drought relief.

Further, the **co-occurrence of drought conditions with intense rainfall resulted in different socio-hydrological processes according to socio-economic and topographic characteristics**. In central-northern Kenya, the heavy rainfall quickly replenished water sources due to the presence of adequate infrastructure (e.g., dams). Additionally, sufficient vegetation cover allowed better retention of rainwater, reducing the development of floods. In the central-western counties of Kenya, on the other hand, the dry and cracked soil caused by the 2 years of drought, combined with the abundant rainfall and the highly variable topography, caused landslides. Finally, in the arid and semi-arid region of Kenya and in the Somali region of Ethiopia, the heavy rains occurred in an area with a lack of infrastructure and a compacted soil, resulting in widespread riverine flooding and flash floods. The flood events washed away boreholes, thereby increasing water shortage and food insecurity. In the latter two cases, negative interactions (increasing impacts) predominated over positive interactions (decreasing impacts) on a short timeframe.

Finally, **drought hazard, impacts and responses influenced the flood risk components**. In particular, the drought hazard led to the degradation of the vegetation cover and the compaction of the soil. Consequently, sub-surface water storage and infiltration were reduced, leading to an increase in the runoff coefficient. This favored the development of flash floods and riverine floods. Drought impacts instead affected the social system's ability to cope with a subsequent flood due to limited recovery time and hence increasing flood vulnerability (Pescaroli & Alexander, 2015). Finally, drought response increased both flood hazard and exposure. During the early rainfall, dam operators were confronted with the decision to capture the early season streamflow or to maintain empty space for flood management purposes. This challenge, coupled with the poor reliability of the long rainy season forecast, led to sudden overspills during heavy rains, which further increased flood risks. At the same time, we found that poor dam maintenance during the drought and poor dam design contributed to the dam failure during the heavy rain. Moreover, some Ethiopian and Kenyan communities, in response to water scarcity due to drought, migrated closer to water sources further increasing their exposure to floods.

The approach proposed in this study can be replicated and scaled up or down to different geographical settings, since it takes into account different methods/evidence types depending on their availability. Once the case study has been selected, spatial and temporal boundaries of the analysis need to be carefully defined. Societal and physical events are continuously interconnected in time and space: current socio-economic and environmental conditions could be the result of past events that occurred in the analyzed area and/or in other inter-connected locations. The use of long time frames may allow to identify patterns in the interaction types that characterize specific multi-hazard events, generalizing the empirical results obtained. It could be that the drought-flood event of 2017–2018 was unique and the identified interactions are not representative of the interplay between consecutive hydrological extremes in Kenya and Ethiopia. At the same time, a long time frame could allow us to take into account the different time scales in which impacts develop and cascade. The spatial resolution used also has an influence on the range of interactions that can be captured. Results of this study show that the same physical and societal drivers could lead to different interactions based on different environmental and socioeconomic contexts. Therefore, as the level of heterogeneity in the area of analysis increases, a finer resolution is needed to be able to capture the wider range of interactions. Finally, the use of a fine resolution and/or large spatial boundaries allow investigating spatial dependencies between events.

7. Conclusions

In this paper, we developed a stepwise, bottom-up approach to unravel spatiotemporal interactions between societal and physical variables during drought-to-flood events in highly vulnerable contexts, looking at two case studies in the Horn of Africa. We explored event timelines, impacts, physical/societal variables and driver-impact interactions through the iterative use of literature review, time series analysis, stakeholder online surveys and stakeholder interviews. This interdisciplinary approach allowed us to move beyond the analysis of interactions of physical drivers, offering a holistic narrative of relationships underlying drought-to-flood risks and societal events in fragile contexts. Further, the approach helps to overcome limitations on data availability in fragile contexts by making use of (and integrating) different evidence types. Finally, the approach can be used for a wide range of extreme events and multi-risk interaction types (e.g., compounding, cascading), and can be applied to different geographical settings.

Our analysis in Kenya and Ethiopia shows that the drought and flood events in 2017–2018 did not develop in isolation, but their risks stem from multiple, dynamic interactions between risk components, impacts, and responses, closely linked to the contextual fragile conditions. Further, we have seen that cascading and concurrent processes can develop both negative interactions (increasing the impacts) and positive interactions (decreasing the impacts). With this study, we showed the complexity of disaster risk in real-context conditions. Therefore, we encourage the integrated use of qualitative and quantitative methods framed in a bottom-up approach, to conceptualize disaster risks as a set of multiple (societal and physical) events interacting and evolving across space and time.

Data Availability Statement

The data sources used for the time series analysis are listed in Table S5 in Supporting Information S1. The raw data used to develop Figure 2 are available through the Climate Hazards group Infrared Precipitation with Stations (CHIRPS) data set (Funk, 2015, https://www.chc.ucsb.edu/data/chirps), the EM-DAT (CRED, 2020, https://public.emdat.be/) and DesInventar (UNDRR, 2020, https://www.desinventar.net/) databases.

Acknowledgments

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References

Adhikari, P., Hong, Y., Douglas, K. R., Kirschbaum, D. B., Gourley, J., Adler, R., & Brakenridge, G. R. (2010). A digitized global flood inventory (1998–2008): Compilation and preliminary results. *Natural Hazards*, *55*(2), 405–422. https://doi.org/10.1007/s11069-010-9537-2

Alfieri, L., Bisselink, B., Dottori, F., Naumann, G., de Roo, A., Salamon, P., et al. (2017). Global projections of river flood risk in a warmer world. *Earth's Future*, *5*(2), 171–182. https://doi.org/10.1002/2016EF000485

Awobamise, A., Jarrar, Y., & Owade, J. (2020). *An analysis of media reportage of conflict during the 2007, 2013 and 2017 in Kenyan presidential elections: A peace journalism approach* (Vol. 12, pp. 184–191). Universidad y Sociedad.

Ayugi, B., Tan, G., Rouyun, N., Zeyao, D., Ojara, M., Mumo, L., et al. (2020). Evaluation of meteorological drought and flood scenarios over Kenya, East Africa. *Atmosphere*, *11*(3), 307. https://doi.org/10.3390/atmos11030307

Barendrecht, M. H., Viglione, A., & Blöschl, G. (2017). A dynamic framework for flood risk. *Water Security*, *1*, 3–11. https://doi.org/10.1016/j.wasec.2017.02.001

Blair, P., & Buytaert, W. (2016). Socio-hydrological modelling: A review asking "why, what and how?" *Hydrology and Earth System Sciences*, *20*(1), 443–478. https://doi.org/10.5194/hess-20-443-2016

Blöschl, G. (2006). Hydrologic synthesis: Across processes, places, and scales. *Water Resources Research*, *42*(3), W03S02. https://doi.org/10.1029/2005WR004319

Boaz, A., Ashby, D., Young, K., Baldwin, S., Grayson, L., Harden, A., et al. (2002). *ESRC UK Centre for Evidence Based Policy and Practice: Working Paper 2 Systematic Reviews: What have they got to offer evidence based policy and practice?* ESRC UK Centre for Evidence Based Policy and Practice.

Bohensky, E. L., & Leitch, A. M. (2014). Framing the flood: A media analysis of themes of resilience in the 2011 Brisbane flood. *Regional Environmental Change*, *14*(2), 475–488. https://doi.org/10.1007/s10113-013-0438-2

Browne, G. J., & Rogich, M. B. (2001). An empirical investigation of user requirements elicitation: Comparing the effectiveness of prompting techniques. *Journal of Management Information Systems*, *17*(4), 223–249. https://doi.org/10.1080/07421222.2001.11045665

Brunner, M. I., & Gilleland, E. (2021). Complex high- and low-flow networks differ in their spatial correlation characteristics, drivers, and changes. *Water Resources Research*, *57*(9). https://doi.org/10.1029/2021WR030049

Brunner, M. I., Slater, L., Tallaksen, L. M., & Clark, M. (2021). Challenges in modeling and predicting floods and droughts: A review. *Wiley Interdisciplinary Reviews: Water*, *8*(3), e1520. https://doi.org/10.1002/wat2.1520

Bryman, A. (2012). *Social research methods* (Vol. 39, pp. 561–563). Oxford University Press.

Ciurean, R., Gill, J., Reeves, H. J., O'Grady, S., & Aldridge, T. (2018). Review of environmental multi-hazards research and risk assessments (p. 86). Retrieved from http://nora.nerc.ac.uk/id/eprint/524399/

CRED. (2019). Disasters in Africa: 20 year review 2000–2019 (p. 56).

CRED. (2020). EM-DAT Database. http://www.emdat.be/database

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly*, *84*(2), 242–261. https://doi.org/10.1111/1540-6237.8402002

D'Arcy, M., & Nistotskaya, M. (2019). Intensified local grievances, enduring national control: The politics of land in the 2017 Kenyan elections. *Journal of Eastern African Studies*, *13*(2), 294–312. https://doi.org/10.1080/17531055.2019.1590763

Das, A. (2019). Floods after drought: India reels from extremes. Retrieved from https://asiatimes.com/2019/08/floods-after-drought-india-reels-from-extremes/

De Groote, H., Kimenju, S. C., Munyua, B., Palmas, S., Kassie, M., & Bruce, A. (2020). Spread and impact of fall armyworm (Spodoptera frugiperda J.E. Smith) in maize production areas of Kenya. *Agriculture, Ecosystems & Environment*, *292*(December), 106804. https://doi.org/10.1016/j.agee.2019.106804

de Ruiter, M. C., Couasnon, A., van den Homberg, M. J. C., Daniell, J. E., Gill, J. C., & Ward, P. J. (2020). Why we can no longer ignore consecutive disasters. *Earth's Future*, *8*(3). https://doi.org/10.1029/2019EF001425

Di Baldassarre, G., Martinez, F., Kalantari, Z., & Viglione, A. (2017). Drought and flood in the Anthropocene: Feedback mechanisms in reservoir operation. *Earth System Dynamics*, *8*(1), 225–233. https://doi.org/10.5194/esd-8-225-2017

Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Salinas, J. L., & Blöschl, G. (2013). Socio-hydrology: Conceptualising human-flood interactions. *Hydrology and Earth System Sciences*, *17*(8), 3295–3303. https://doi.org/10.5194/hess-17-3295-2013

European Commission. (2020). Humanitarian Implementation Plan (HIP) Latin America and the Caribbean (pp. 1–23).

FEWS NET. (2018). Kenya Food Security Outlook: June 2017 to January 2018. Kenya Food Security Outlook, June 2017.

FEWS NET. (2019). Ethiopia: Food Security Outlook: October 2018 to May 2019. Retrieved from https://reliefweb.int/sites/reliefweb.int/files/resources/ETHIOPIA_Food_Security_Outlook_October2018.pdf

Formetta, G., & Feyen, L. (2019). Empirical evidence of declining global vulnerability to climate-related hazards. *Global Environmental Change*, *57*, 101920. https://doi.org/10.1016/j.gloenvcha.2019.05.004

Funk, C. (2015). Climate Hazards Group Infrared Precipitation with Stations - CHIRPS. https://doi.org/10.15780/G2RP4Q

Funk, C., Hoell, A., Nicholson, S., Korecha, D., Galu, G., Artan, G., et al. (2019). Examining the potential contributions of extreme "Western V" sea surface temperatures to the 2017 March–June East African Drought. *Bulletin of the American Meteorological Society*, *100*(1), S55–S60. https://doi.org/10.1175/BAMS-D-18-0108.1

Gallina, V., Torresan, S., Critto, A., Sperotto, A., Glade, T., & Marcomini, A. (2016). A review of multi-risk methodologies for natural hazards: Consequences and challenges for a climate change impact assessment. *Journal of Environmental Management*, *168*, 123–132. https://doi.org/10.1016/j.jenvman.2015.11.011

Garcia, M., Ridolfi, E., & Di Baldassarre, G. (2020). The interplay between reservoir storage and operating rules under evolving conditions. *Journal of Hydrology*, *590*, 125270. https://doi.org/10.1016/j.jhydrol.2020.125270

Gill, J. C., & Malamud, B. D. (2014). Reviewing and visualizing the interactions of natural hazards. *Reviews of Geophysics*, *52*(4), 680–722. https://doi.org/10.1002/2013RG000445

Gill, J. C., & Malamud, B. D. (2017). Anthropogenic processes, natural hazards, and interactions in a multi-hazard framework. *Earth-Science Reviews*, *166*, 246–269. https://doi.org/10.1016/j.earscirev.2017.01.002

Gill, J. C., Malamud, B. D., Barillas, E. M., & Noriega, A. G. (2020). Construction of regional multi-hazard interaction frameworks, with an application to Guatemala. *Natural Hazards and Earth System Sciences*, *20*(1), 149–180. https://doi.org/10.5194/nhess-20-149-2020

Hagenlocher, M., Meza, I., Anderson, C. C., Min, A., Renaud, F. G., Walz, Y., et al. (2019). Drought vulnerability and risk assessments: State of the art, persistent gaps, and research agenda. *Environmental Research Letters*, *14*(8), 083002. https://doi.org/10.1088/1748-9326/ab225d

Henn, B., Musselman, K. N., Lestak, L., Ralph, F. M., & Molotch, N. P. (2020). Extreme runoff generation from atmospheric river driven snowmelt during the 2017 Oroville dam spillways incident. *Geophysical Research Letters*, *47*(14). https://doi.org/10.1029/2020GL088189

Hillier, J. K., Matthews, T., Wilby, R. L., & Murphy, C. (2020). Multi-hazard dependencies can increase or decrease risk. *Nature Climate Change*, *10*(7), 595–598. https://doi.org/10.1038/s41558-020-0832-y

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., et al. (2013). Global flood risk under climate change. *Nature Climate Change*, *3*(9), 816–821. https://doi.org/10.1038/nclimate1911

Huho, J. M., & Kosonei, R. C. (2014). Understanding extreme climatic events for economic development in Kenya. *IOSR Journal of Environmental Science, Toxicology and Food Technology*, *8*(2), 14–24. https://doi.org/10.9790/2402-08211424

Huning, L. S., & AghaKouchak, A. (2020). Global snow drought hot spots and characteristics. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(33), 19753–19759. https://doi.org/10.1073/PNAS.1915921117

Huntington, T. G. (2006). Evidence for intensification of the global water cycle: Review and synthesis. *Journal of Hydrology*, *319*(1–4), 83–95. https://doi.org/10.1016/j.jhydrol.2005.07.003

IFRC. (2020a). Operation Update Report Afghanistan: Drought and Flash Floods. Retrieved from https://reliefweb.int/report/afghanistan/afghanistan-drought-and-flash-floods-emergency-appeal-n-mdraf005-epoa-update-n-5

IFRC. (2020b). World Disasters Report 2020: Come Heat or High Water. In *World Disaster Report 2020*. Retrieved from https://www.ifrc.org/sites/default/files/2021-05/20201116_WorldDisasters_Full.pdf

IPCC. (2021). Climate change 2021: The physical science basis (Vol. *92*, pp. 86–87).

Kassegn, A., & Endris, E. (2021). Review on socio-economic impacts of "Triple Threats" of COVID-19, desert locusts, and floods in East Africa: Evidence from Ethiopia. *Cogent Social Sciences*, *7*(1), 1885122. https://doi.org/10.1080/23311886.2021.1885122

Katuva, J., Hope, R., Foster, T., Koehler, J., & Thomson, P. (2020). Groundwater and welfare: A conceptual framework applied to coastal Kenya. *Groundwater for Sustainable Development*, *10*, 100314. https://doi.org/10.1016/j.gsd.2019.100314

Kilavi, M., MacLeod, D., Ambani, M., Robbins, J., Dankers, R., Graham, R., et al. (2018). Extreme rainfall and flooding over central Kenya including Nairobi city during the long-rains season 2018: Causes, predictability, and potential for early warning and actions. *Atmosphere*, *9*(12), 472. https://doi.org/10.3390/atmos9120472

Konar, M., Garcia, M., Sanderson, M. R., Yu, D. J., & Sivapalan, M. (2019). Expanding the scope and foundation of sociohydrology as the science of coupled human-water systems. *Water Resources Research*, *55*(2), 874–887. https://doi.org/10.1029/2018WR024088

Kreibich, H., Blauhut, V., Aerts, J. C. J. H., Bouwer, L. M., Van Lanen, H. A. J., Mejia, A., et al. (2019). How to improve attribution of changes in drought and flood impacts. *Hydrological Sciences Journal*, *64*(1), 18. https://doi.org/10.1080/02626667.2018.1558367

Kumela, T., Simiyu, J., Sisay, B., Likhayo, P., Mendesil, E., Gohole, L., & Tefera, T. (2019). Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (*Spodoptera frugiperda*) in Ethiopia and Kenya. *International Journal of Pest Management*, *65*(1), 9. https://doi.org/10.1080/09670874.2017.1423129

Lavers, T. (2018). Responding to land-based conflict in Ethiopia: The land rights of Ethnic minorities under federalism. *African Affairs*, *117*(468), 462–484. https://doi.org/10.1093/afraf/ady010

Leonard, M., Westra, S., Phatak, A., Lambert, M., van den Hurk, B., Mcinnes, K., et al. (2014). A compound event framework for understanding extreme impacts. *Wiley Interdisciplinary Reviews: Climate Change*, *5*(1), 113–128. https://doi.org/10.1002/wcc.252

MacDougall, C., & Fudge, E. (2001). Planning and recruiting the sample for focus groups and in-depth interviews. *Qualitative Health Research*, *11*(1), 117–126. https://doi.org/10.1177/104973201129118975

Madruga De Brito, M., Kuhlicke, C., & Marx, A. (2020). Near-real-time drought impact assessment: A text mining approach on the 2018/19 drought in Germany. *Environmental Research Letters*, *15*(10), 1040a9. https://doi.org/10.1088/1748-9326/aba4ca

Mazzoleni, M., Odongo, V. O., Mondino, E., & Di Baldassarre, G. (2021). Water management, hydrological extremes, and society: Modeling interactions and phenomena. *Ecology and Society*, *26*(4), 4. https://doi.org/10.5751/es-12643-260404

Njogu, H. W. (2021). Effects of floods on infrastructure users in Kenya. *Journal of Flood Risk Management*, *14*(4), e12746. https://doi.org/10.1111/jfr3.12746

Pande, S., & Sivapalan, M. (2017). Progress in socio-hydrology: A meta-analysis of challenges and opportunities. *WIREs Water*, *4*(4), e1193. https://doi.org/10.1002/wat2.1193

Pescaroli, G., & Alexander, D. (2015). A definition of cascading disasters and cascading effects: Going beyond the "toppling dominos" metaphor. *GRF Davos Planet@Risk*, *3*(1), 58–67.

Peters, K., Holloway, K., & Peters, L. E. R. (2019). Disaster risk reduction in conflict contexts: The state of the evidence.

Peterson, T. J., Saft, M., Peel, M. C., & John, A. (2021). Watersheds may not recover from drought. *Science*, *372*(6543), 745–749. https://doi.org/10.1126/science.abd5085

Philip, S., Kew, S. F., van Oldenborgh, G. J., Otto, F., O'Keefe, S., Haustein, K., et al. (2018). Attribution analysis of the Ethiopian drought of 2015. *Journal of Climate*, *31*(6), 2465–2486. https://doi.org/10.1175/JCLI-D-17-0274.1

Pitts, M. G., & Browne, G. J. (2004). Stopping behavior of systems analysts during information requirements elicitation. *Journal of Management Information Systems*, *21*(1), 203–226. https://doi.org/10.1080/07421222.2004.11045795

Pott, S. (2020). Drought, Locusts, coronavirus, and now a once-in-a-century flood. Retrieved from https://www.welthungerhilfe.org/news/press-releases/2020/flooding-in-east-africa/

Prudhomme, C., Parry, S., Hannaford, J., Clark, D. B., Hagemann, S., & Voss, F. (2011). How well do large-scale models reproduce regional hydrological extremes: In Europe? *Journal of Hydrometeorology*, *12*(6), 1181–1204. https://doi.org/10.1175/2011JHM1387.1

Raymond, C., Horton, R. M., Zscheischler, J., Martius, O., AghaKouchak, A., Balch, J., et al. (2020). Understanding and managing connected extreme events. *Nature Climate Change*, *10*(7), 611–621. https://doi.org/10.1038/s41558-020-0790-4

Ridder, N. N., Pitman, A. J., Westra, S., Ukkola, A., Hong, X. D., Bador, M., et al. (2020). Global hotspots for the occurrence of compound events. *Nature Communications*, *11*(1), 5956. https://doi.org/10.1038/s41467-020-19639-3

Saft, M., Western, A. W., Zhang, L., Peel, M. C., & Potter, N. J. (2015). The influence of multiyear drought on the annual rainfall-runoff relationship: An Australian perspective. *Water Resources Research*, *51*(4), 2444–2463. https://doi.org/10.1002/2014WR015348

Schur, D. (1998). An introduction to close reading. Retrieved from https://media.gradebuddy.com/documents/2651162/2e637c34-5bca-4e19-af0a-ed3c86596017.pdf

Simpson, N. P., Mach, K. J., Constable, A., Hess, J., Hogarth, R., Howden, M., et al. (2021). A framework for complex climate change risk assessment. *One Earth*, *4*(4), 489–501. https://doi.org/10.1016/j.oneear.2021.03.005

Skøien, J. O., Blöschl, G., & Western, A. W. (2003). Characteristic space scales and timescales in hydrology. *Water Resources Research*, *39*(10). https://doi.org/10.1029/2002WR001736

Solomon, N., Birhane, E., Gordon, C., Haile, M., Taheri, F., Azadi, H., & Scheffran, J. (2018). Environmental impacts and causes of conflict in the Horn of Africa: A review. *Earth-Science Reviews*, *177*, 284–290. https://doi.org/10.1016/j.earscirev.2017.11.016

Stahl, K., & Hisdal, H. (2004). Hydroclimatology. In *Developments in Water Sciences* (Vol. 48, pp. 19–51).

Stahl, K., Kohn, I., Blauhut, V., Urquijo, J., De Stefano, L., Acácio, V., et al. (2016). Impacts of European drought events: Insights from an international database of text-based reports. *Natural Hazards and Earth System Sciences*, *16*(3), 801–819. https://doi.org/10.5194/nhess-16-801-2016

Tabari, H., Hosseinzadehtalaei, P., Thiery, W., & Willems, P. (2021). Amplified drought and flood risk under future socioeconomic and climatic change. *Earth's Future*, *9*(10), 1–24. https://doi.org/10.1029/2021ef002295

Tilloy, A., Malamud, B. D., Winter, H., & Joly-Laugel, A. (2019). A review of quantification methodologies for multi-hazard interrelationships. *Earth-Science Reviews*, *196*, 102881. https://doi.org/10.1016/j.earscirev.2019.102881

Uhe, P., Philip, S., Kew, S., Shah, K., Kimutai, J., Mwangi, E., et al. (2018). Attributing drivers of the 2016 Kenyan drought. *International Journal of Climatology*, *38*(December), e554–e568. https://doi.org/10.1002/joc.5389

Ullrich, P. A., Xu, Z., Rhoades, A. M., Dettinger, M. D., Mount, J. F., Jones, A. D., & Vahmani, P. (2018). California's drought of the future: A midcentury recreation of the exceptional conditions of 2012–2017. *Earth's Future*, *6*(11), 1568–1587. https://doi.org/10.1029/2018EF001007

UNDRR. (2019). GAR2019—chapter 15: Disaster risk reduction strategies in fragile and complex risk contexts. 425 (Peters 2018) (pp. 407–425). Retrieved from https://gar.undrr.org/report-2019

UNDRR. (2020). DesInventar Database. United Nations Office for disaster risk reduction. https://www.desinventar.net/

Van Loon, A. F. (2015). Hydrological drought explained. *WIREs Water*, *2*(4), 359–392. https://doi.org/10.1002/wat2.1085

Van Loon, A. F., Stahl, K., Di Baldassarre, G., Clark, J., Rangecroft, S., Wanders, N., et al. (2016). Drought in a human-modified world: Reframing drought definitions, understanding, and analysis approaches. *Hydrology and Earth System Sciences*, *20*(9), 3631–3650. https://doi.org/10.5194/hess-20-3631-2016

Ward, P. J., Blauhut, V., Bloemendaal, N., Daniell, E. J., De Ruiter, C. M., Duncan, J. M., et al. (2020). Review article: Natural hazard risk assessments at the global scale. *Natural Hazards and Earth System Sciences*, *20*(4), 1069–1096. https://doi.org/10.5194/nhess-20-1069-2020

Ward, P. J., de Ruiter, M. C., Mård, J., Schröter, K., Van Loon, A., Veldkamp, T., et al. (2020). The need to integrate flood and drought disaster risk reduction strategies. *Water Security*, *11*, 100070. https://doi.org/10.1016/j.wasec.2020.100070

Wens, M., Johnson, J. M., Zagaria, C., & Veldkamp, T. I. E. (2019). Integrating human behavior dynamics into drought risk assessment—A sociohydrologic, agent-based approach. *WIREs Water*, *6*(4), e1345. https://doi.org/10.1002/wat2.1345

White, G. (1945). Human adjustment to floods. In *Geography, Resources and Environment* (Vol. 5).

Wohlin, C. (2014). Guidelines for snowballing in systematic literature studies and a replication in software engineering. In *Proceedings of the ACM International Conference Proceeding Series*. https://doi.org/10.1145/2601248.2601268

Zscheischler, J., Martius, O., Westra, S., Bevacqua, E., Raymond, C., Horton, R. M., et al. (2020). A typology of compound weather and climate events. *Nature Reviews Earth & Environment*, *1*(7), 333–347. https://doi.org/10.1038/s43017-020-0060-z

Zscheischler, J., Westra, S., Van Den Hurk, B. J. J. M., Seneviratne, S. I., Ward, P. J., Pitman, A., et al. (2018). Future climate risk from compound events. *Nature Climate Change*, *8*(6), 469–477. https://doi.org/10.1038/s41558-018-0156-3

References From the Supporting Information

Di Baldassarre, G., Viglione, A., Carr, G., Kuil, L., Yan, K., Brandimarte, L., & Blöschl, G. (2015). Debates: Perspectives on socio-hydrology: Capturing feedbacks between physical and social processes. *Water Resources Research*, *51*(6), 4770–4781. https://doi.org/10.1002/2014WR016416

Joint Government and Humanitarian Partners. (2018). Ethiopia: Humanitarian and disaster resilience plan. Retrieved from https://reliefweb.int/sites/reliefweb.int/files/resources/ethiopia_2018_humanitarian_and_disaster_resilience_plan.pdf

UNDRR. (2021). UNDRR: Terminology. Retrieved from https://www.undrr.org/terminology

Viste, E., Korecha, D., & Sorteberg, A. (2012). Recent drought and precipitation tendencies in Ethiopia. *Theoretical and Applied Climatology*, *112*(3–4), 535–551. https://doi.org/10.1007/s00704-012-0746-3