Drought-flood Underlying Interactions over Global Environments

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Key Points:

- Droughts abruptly transformed into/followed by floods caused by heavy rainfall events globally.
- Propagation mechanisms, evolutions, drivers, and causes underlying drought-flood interactions are yet to be investigated in detail.
- Whether drought is taking the triggering role for the flood to occur or the other way round is also unknown worth of attentions.

Abstract

Drought and floods affect the structure, composition, and the function of global environments and thus human societies. Although several studies exist on both droughts and floods, studies on whether droughts can be a means to cause floods or vice versa are lacking in the literature. However, it has been repeatedly said that after a severe drought season, there is heavy rainfall and thus flooding. Using different global terrestrial ecosystems from across the globe, understanding the underlying mechanisms, evolutions, and drivers of how droughts can abruptly cause flooding or vice versa on a global scale representing drought-flood hotspot regions from both the Northern and Southern Hemispheres is indispensable. Considering drought hotspot areas across the globe such as the 2000s Australia's Millennium drought, and the 2010/11 Horn of Africa drought that experienced large-scale flooding in the aftermath of drought is crucial. Subject to analysis and interpretations, the study findings of drought-flood underlying interactions reveal major contributions to the growing field of drought hydrology for future policymaking.

Plain Language Summary

The commentary highlights flood-drought interactions as an interesting area of hydrology and one that is poorly understood as to which drought conditions increase the probability of subsequent flooding or otherwise and indeed how these compound drought-flood events might change with climate change. As such, this commentary outlines an important avenue for future research due to the severe societal impacts such compound events have had in the past. This argument is made because understanding the underlying link between drought and flood is worth increased attention by the research community that would provide insights for policymaking.

1 Introduction

Natural disasters have been caused large-scale economic and humanitarian tolls in the last two decades. By far extreme climate events have resulted in ca. 2.3 trillion USD in damages, revealing a 68% increase over the last 20 years (Pascaline et al., 2018). Drought and flood are among the important extreme climatic events for human-natural systems. These extreme events have been observed for the continued intensification of food and price disruptions globally. Thus, quantifying extreme climate events in terms of their impacts and the exposure of society, economy, and environment over different areas and time scales is of pressing importance. Droughts and floods are potentially interrelated and are governed by similar hydrological and atmospheric processes.

Drought affects the structure, composition, and the function of global environments and thus human societies. Over the last two decades, severe drought events have occurred across the globe. Examples of drought hotspot areas from across the globe including; southeast Australia's Millennium drought (Kiem et al., 2016; Van Dijk et al., 2013), the 2010/11 Horn of Africa drought (Haile et al., 2019; Nicholson, 2014), the 2003 central Europe drought/heat wave (Garcia-Herrera et al., 2010), the 2013/2014 California drought (Mann and Gleick, 2015), the 2010 Russian drought (Spinoni et al., 2015), the 2014 North China drought (Wang and He, 2015), the 2022 China's Yangtze River basin drought (Toreti et al., 2022; Zhang et al., 2023a) and the 2015–2017 Southern Africa drought (Muller, 2018). In addition, droughts impacted 1.5 billion people during 1998–2017 (Pascaline et al., 2018) and about 430 million people during 2015–2018 (EM-DAT, 2019). These droughts account for about 33 billion USD economic losses and have become a means for the recent increase in global hunger (FAO, 2017). Broadly, droughts create natural environments and socioeconomic system disruption across the world (Haile et al., 2019; Van Loon, 2015). Impacts include crop failure, food shortage, famine, epidemics, and even mass migration (Nangombe et al., 2018; Zhou et al., 2018). Thus, droughts have led to an increase of about 70% in extreme food insecurity in the last two decades (Funk et al., 2019b, 2019a).

Similarly, floods affect various natural environments and socioeconomic sectors. Flooding is extreme weather caused by heavy precipitation magnitude and extent. The main reason for flooding is heavy rainfall, which can be caused by a variety of factors, including seasonal changes, tropical storms, and climate patterns such as El Niño. Flooding has led to annual mean economic losses of nearly 15.1 billion USD since the 1960s (Gu et al., 2022). Recently, Africa was struck by tropical cyclones which imposed catastrophic impacts. This hazardous flooding has posed widespread flooding and strong winds causing over 1000 fatalities, and one billion USD in economic damages in Madagascar, Malawi, Mozambique, and Zimbabwe (Lavers et al., 2019). In 2021 alone, 223 flood events were reported globally, including in China, India, Afghanistan, and Germany (Gu et al., 2022; Ren et al., 2023). However, the ability of society to respond to flood timing, volume, and magnitude is very crucial, which is lacking in less developed countries.

2. Drought-flood underlying interactions

Droughts and flooding are linked through the interaction between precipitation variability, soil moisture, infiltration capacity, seasonal water balance and runoff, highlighting the importance of understanding the complex dynamics of water in the natural environment (Trenberth et al., 2014; IPCC, 2022). In addition, drought and flood can have complex underlying interactions that vary depending on factors such as timing, intensity, and regional climate patterns. In some cases, drought can increase the risk of flash flooding by leaving the soil dry and unable to absorb significant rainfall, leading to hazardous runoff. Conversely, heavy flooding can cause soil erosion and disrupt the ecosystem, leading to decreased soil moisture and an increased likelihood of drought.

On the other hand, a flood may break a drought by replenishing dry soil, but it may also exacerbate future droughts by increasing the likelihood of soil erosion and decreasing the water-holding capacity of the land. Additionally, droughts can lead to a greater likelihood of flash flooding due to the lack of vegetation and hardened soil, which is unable to absorb water. These results suggest that floods and droughts have complex and often interrelated impacts on each other. Therefore, it is important to consider the context and specific circumstances when discussing the interplay between drought and flood.

Moreover, climate change is leading to more extreme weather events, which can exacerbate the underlying interactions between drought and flood (IPCC, 2022). State-of-the-art models projected higher frequency and intensity of droughts and floods across the Southern and Northern Hemispheres in response to global climate change (IPCC, 2013; Thober et al., 2018; Trenberth et al., 2014). Most prominently, the past decade has experienced faster and unprecedented warming trends suggesting an examination of the terrestrial ecosystem responses to drought extremes. Furthermore, anthropogenic climate change is projected to potentially exacerbate future flood events. The occurrence of extreme climatic events depends on precipitation, antecedent land conditions, land surface characteristics, water management, and social response. Thus, a focused action is needed on natural hazards to minimize their impacts on the environment and society.

3. Drought-flood abrupt alternations

Extreme climate hazards such as drought and flooding have a devastating impact on the well-being of livelihoods and ecosystem functioning. Of these natural hazards, the root cause of droughts and flooding is mainly either excess or shortage of precipitation. These climate extremes are much more complicated events with complex cascading and propagation impacts. Drought-flood compound events are caused by various factors such as natural climate variability, climate change, land use changes, and local conditions. Thus, a deep understanding of these extreme but opposite events abruptly spells each other with a unique causing mechanism (mainly precipitation) is vital. For example, immediately after the severe 2010/11 Horn of Africa drought, devastating floods followed, which caused additional impacts on society. As explained by van Genderen (2012), a famous Australian poet written more than a hundred years ago (around 1867-1922) said 'Droughts this year, floods next season' which exactly was true as the 2000s millennium Australian drought ended up with massive flooding in the Murray-Darling Basin. Notably, the abrupt alterations are different from normal dry-wet or drying-rewetting cycling, but it is a period of persistent drought suddenly transformed into/followed by heavy precipitation. For instance, on May 17, 2023, devastating floods hit Italy's Emilia-Romagna, causing casualties where the region is transformed from drought to flooding in an almost one month break from a consecutive two years drought. Recent publications defined dry-wet abrupt alternation as the phenomenon of dry (or wet) spells abruptly transformed to/followed by wet (or dry) spells (Chen et al., 2020; Bi et al., 2023; Ren et al., 2023; Zhang et al., 2023b). However, evidence of whether the severe drought was the main cause for such a flash flooding evolution or vice versa is still lacking in the literature. Understanding the dynamic evolution of these abrupt shifts between drought and flood events consecutively in short periods is worthwhile. The combined superposition effect of the drought-flood alteration disasters is far greater than their respective individual disasters, posing serious threats to ecological security, food production, and human safety (Bi et al., 2023; Zhang et al., 2023b).

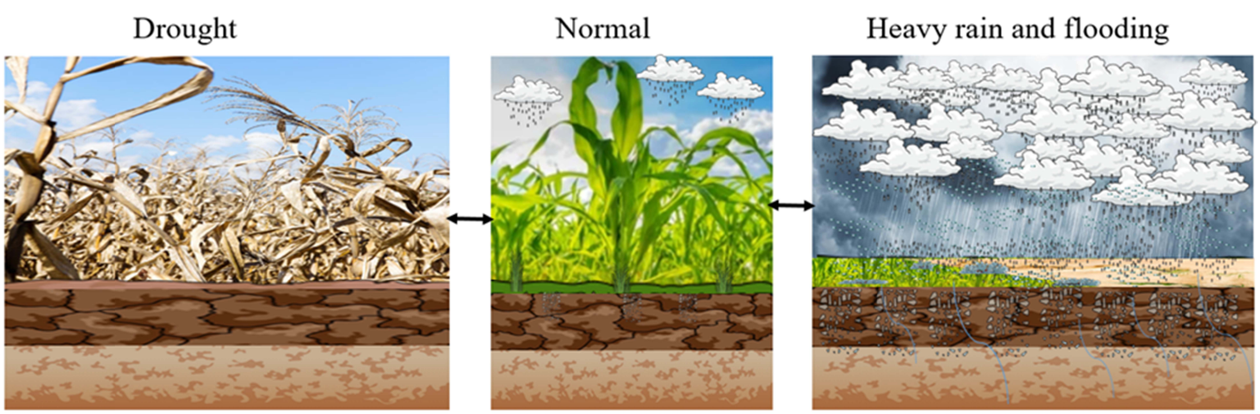

Figure 1: Drought-flood abrupt shift process diagram.

Drought and flood play a fundamental role in global water cycle processes. In the 21st century, both alternately are expected to be more prevalent, intensified, and lengthened across the globe in various magnitudes (Haile et al., 2019; Haile et al., 2020a; IPCC, 2022). The drought-flood alterations are also expected to increase in the 21st century, especially in China, based on observations and model simulations (Zhang et al., 2023b). Thus, studying the underlying hydrometeorological linkages/ propagating interactions that exist between severe droughts and flash flooding is crucial. The interaction and propagation abilities between the opposing climate extreme events should be the subject of scientists and policymakers. The motivation here is to initially understand the existing situation on the drought-flood interactions, causing mechanisms between one another and assessment of the social perceptions. The identified drought-flood hotspot areas in the mid-latitude region, tropical area, and burial regions are essential subjects for further investigation. For this purpose, drought-flood hotspot areas in the mid-latitude region, in low (tropical area), and high (burial area) latitude regions representing global terrestrial ecosystems are of crucial importance to capture the interactions globally. High-resolution precipitation datasets from different reliable sources and drought and flood impact data from the global Emergency Events Database (EMDAT) (http://www.emdat.be/database) (EM-DAT, 2018) along with social perceptions collected from an intensive questionnaire to investigate peoples understanding of drought-flood interactions are also required for detailed investigations of the available interactions. The quantification of both drought-flood interactions is therefore necessary considering the compounding behavior, cascading effects, and propagation impacts of their underlying interactions. This will be helpful to capture the entire length of the drought-flood interactions.

4. Drought-flood compound events, cascading effects, and propagation impacts

Drought-flood compound events refer to the occurrence of consecutive or simultaneous extreme weather conditions of both drought and flood, which can cause significant damage to ecosystems, agriculture, and human societies. These events can occur due to several factors, including climate change, land-use change, temperature changes and natural variability (IPCC, 2022). Droughts and floods are interconnected weather phenomena. Drought conditions can lead to soil degradation and reduced vegetation, resulting in a lower water-holding capacity and increased soil erosion. Hence, when heavy rainfall occurs after a prolonged drought, it can cause flash floods, landslides, and soil erosion. Moreover, flood events can worsen drought conditions by flushing out the topsoil and washing away the seeds, ultimately reducing the soil's fertility and further reducing water availability. These suggest that droughts and floods compound each other, with one event leading to another, leaving little time for the soil to recover.

The cascading effects of droughts and floods can have a significant impact on people and the environment (Garcia-Herrera et al., 2010, Haile et al., 2020b). They can lead to food shortages, water shortages, economic losses, health problems, and in the worst case, loss of life. There are several cascading effects and propagation impacts that occur between floods and droughts. For instance, floods can lead to contamination of water sources, which may exacerbate the spread of waterborne diseases during droughts. Similarly, droughts can lead to the drying up of riverbeds, which can increase the likelihood of flash floods in the future.

The frequency and severity of drought-flood compound events, cascading effects, and propagation impacts are increasing globally due to climate change impacts (IPCC, 2022). The rising temperature and changing precipitation patterns have caused more frequent dry spells, leading to drought conditions. At the same time, the increased intensity and duration of rainfall have resulted in more severe floods. Thus, understanding and managing drought-flood compound events, cascading effects, and propagation impacts are crucial to reduce the associated risks and losses. Effective water management and land-use practices can reduce the impacts of these events. Developing early warning systems, preparedness plans, and resilient infrastructure can also help mitigate these risks. Overall, the complex interactions between floods and droughts underscore the importance of holistic and adaptive management strategies that consider both phenomena holistically. Understanding these interactions can help communities prepare for and mitigate the impacts of floods and droughts in more effectively.

5. Conclusion

Extreme drought abruptly spelled by heavy rainfall (causing flooding) is bringing tougher challenges to vulnerable populations than their individual counterparts. It is essential to investigate the evolution that can strengthen society's resilience to compound drought and flood events. This commentary assessed and highlighted the possibility of drought-flood interactions globally. Detailed investigations are required to provide a road map and better understand the drought-flood interactions and cascading compound events using the following key questions that are important to provide insights to the research community and policymakers.

Key research questions to be addressed include:

i) When and how droughts do abruptly transformed into/followed by floods caused by heavy rainfall globally?

ii) What are the key propagation mechanisms, evolutions, drivers, and causes underlying drought-flood interactions?

iii) Is drought takes the triggering role for the flood to occur or vice versa?

iv) What are the social perceptions, emotions, and beliefs on drought-flood interactions and propagating mechanisms?

Finding answers to these questions could have pressing importance for decision-makers globally as they broadly help to better understand the flood and drought hazards and mitigate their impacts in the present and future climate projections. Thus, enhancing the understanding of the underlying drought-flood interactions is therefore invaluable for governments, practitioners, and more broadly the general public.

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