Flash Drought Typologies and Societal Impacts

A Worldwide Review of Occurrence, Nomenclature, and Experiences of Local Populations

Walker, David W.; Vergopolan, Noemi; Cavalcante, Louise; Smith, Kelly Helm; Agoungbome, Sehouevi Mawuton David; Almagro, André; Apurv, Tushar; Dahal, Nirmal Mani; Hoffmann, David; More Authors

DOI
10.1175/WCAS-D-23-0015.1

Publication date
2023

Document Version
Final published version

Published in
Weather, Climate, and Society

Citation (APA)
Walker, D. W., Vergopolan, N., Cavalcante, L., Smith, K. H., Agoungbome, S. M. D., Almagro, A., Apurv, T., Dahal, N. M., Hoffmann, D., & More Authors (2023). Flash Drought Typologies and Societal Impacts: A Worldwide Review of Occurrence, Nomenclature, and Experiences of Local Populations. *Weather, Climate, and Society*, *16*(1), 3-28. https://doi.org/10.1175/WCAS-D-23-0015.1

VOLUME 16 WEATHER, CLIMATE, AND SOCIETY JAN-MAR 2024

REVIEW

Flash Drought Typologies and Societal Impacts: A Worldwide Review of Occurrence, Nomenclature, and Experiences of Local Populations

DAVID W. WALKER,[a] NOEMI VERGOPOLAN,[b,c] LOUISE CAVALCANTE,[d] KELLY HELM SMITH,[e]
SEHOUEVI MAWUTON DAVID AGOUNGBOME,[f] ANDRÉ ALMAGRO,[g] TUSHAR APURV,[h] NIRMAL MANI DAHAL,[i,j]
DAVID HOFFMANN,[k] VISHAL SINGH,[h] AND ZHANG XIANG[l]

[a] *Water Resources Management Group, Wageningen University, Wageningen, Netherlands*
[b] *Atmospheric and Ocean Sciences Program, Princeton University, Princeton, New Jersey*
[c] *NOAA/Geophysical Fluid Dynamics Laboratory, Princeton, New Jersey*
[d] *Public Administration and Policy Group, Wageningen University, Wageningen, Netherlands*
[e] *National Drought Mitigation Center, University of Nebraska–Lincoln, Lincoln, Nebraska*
[f] *Water Resources Management Department, TU Delft, Delft, Netherlands*
[g] *Faculty of Engineering and Geography, Federal University of Mato Grosso do Sul, Campo Grande, Brazil*
[h] *Department of Civil Engineering, Indian Institute of Technology Kanpur, Kanpur, India*
[i] *People in Need, Kathmandu, Nepal*
[j] *The Institute of Fundamental Research and Studies, Kathmandu, Nepal*
[k] *Bureau of Meteorology, Melbourne, Victoria, Australia*
[l] *National Engineering Research Center of Geographic Information System, School of Geography and Information Engineering, China University of Geosciences (Wuhan), Wuhan, China*

(Manuscript received 8 February 2023, in final form 31 August 2023, accepted 29 September 2023)

ABSTRACT: Flash droughts, characterized by rapid onset and intensification, are increasingly occurring as a consequence of climate change and rising temperatures. However, existing hydrometeorological definitions fail to encompass the full range of flash droughts, many of which have distinct local physical attributes. Consequently, these events often go undetected or unforecast in generic global flash drought assessments and are underrepresented in research. To address this gap, we conducted a comprehensive survey to gather information on local nomenclature, characteristics, and impacts of flash droughts worldwide. The survey revealed the widespread occurrence of these phenomena, highlighting their underresearched nature. By analyzing case studies, through literature review often in local languages to unearth elusive studies, we identified five different types of flash droughts based on their specific characteristics. Our study aims to increase awareness about the complexity and diverse impacts of flash droughts, emphasizing the importance of considering regional contexts and the vulnerability of affected populations. The reported impacts underscore the need for better integration of all flash drought types in drought research, monitoring, and management. Monitoring a combination of indicators is crucial for timely detection and response to this emerging and escalating threat.

SIGNIFICANCE STATEMENT: This study aims to better understand flash droughts worldwide and their varying characteristics and impacts. We surveyed the experiences of people affected by flash droughts and then examined a wide range of literature, including non-English and nonacademic sources. This helped us understand how flash droughts can differ from those commonly studied in the United States and China. We identified and described five types of flash droughts, some of which may not be detected by current drought measurement methods. It is crucial to include all types of flash droughts in drought monitoring systems and management plans, as they are expected to become more common due to global warming. We can then better prepare for and reduce the impacts of this growing threat.

KEYWORDS: Drought; Extreme events; Climate change; Communications/decision-making; Societal impacts; Vulnerability

1. Introduction

Drought is considered the natural hazard that affects the highest number of people, and it is becoming more frequent and widespread, with increasing economic costs (Wilhite et al. 2014; United Nations Convention to Combat Desertification 2022; Zhao and Dai 2022). It is the prolonged "mega-droughts" that regularly feature in the news, such as, in mid-2022, in the

---

Denotes content that is immediately available upon publication as open access.

Corresponding author: David W. Walker, david.walker@wur.nl

DOI: 10.1175/WCAS-D-23-0015.1

southwest United States (Leonard 2022) and the Horn of Africa (Associated Press 2022), leading to empty reservoirs and famine, respectively. However, at the opposite end of the drought spectrum, both the research and drought management communities are increasingly acknowledging the occurrence of flash drought [see Lisonbee et al. (2021) for a history of the use of the term]. In contrast to how drought is traditionally thought of as a slowly developing hazard, flash drought is characterized by rapid onset and intensification. Flash drought is therefore challenging to forecast, allowing less time to prepare for or mitigate impacts (Hoerling et al. 2014; Otkin et al. 2018). What is more, anthropogenic warming is projected to increase flash drought occurrence and rate of intensification in the coming decades (Yuan et al. 2019; Shah et al. 2022; Qing et al. 2022; Yuan et al. 2023; Walker and Van Loon 2023; Christian et al. 2023).

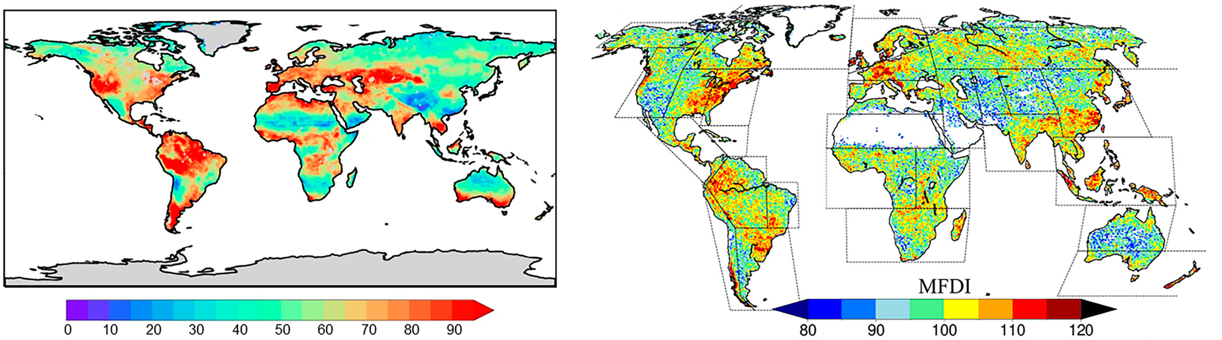
Meteorological droughts are inherently driven by precipitation deficit. The speed with which that drought develops and evolves into soil moisture (agricultural) and ecological drought can be accelerated by above-normal evaporative demand, caused by high temperatures, low humidity, and strong winds (Otkin et al. 2018). It is important to note that many of these drivers are also associated with heat waves, which could accompany flash droughts. While heat waves are defined as periods with extreme high temperatures, the term "flash drought" is used for periods with rapid drying. Dry spells, on the other hand, are defined based on precipitation deficits in a certain period. The rapid drying of soils and vegetation during flash droughts may be caused by high temperatures of heat waves, precipitation deficits of dry spells, and other factors leading to high evaporative demand.

A combination of high precipitation deficit and abnormally high temperatures created flash drought conditions across much of the United States in 2012 and across the northern United States in 2017 resulting in billions of U.S. dollars in agricultural losses, widespread wildfires, poor air quality, damaged ecosystems, and degraded mental health (Otkin et al. 2018; Hoell et al. 2020). Similarly, in southern China in 2011 and 2013, flash droughts driven by precipitation deficit and abnormally high temperatures caused agricultural losses on the order of billions of U.S. dollars (Yuan et al. 2015). The majority of flash drought research has focused on and originated from those two example countries, the United States and China. Consequently, definitions are predominantly based on flash drought characteristics in those regions. From the 50+ publications devoted to flash drought, there was no universally accepted definition (up to July 2020; Lisonbee et al. 2021). Rapid onset varied from 5 days to 8 weeks. Some consider flash drought to be characteristically of short duration, for example, 1–2 pentads or a month (due to the temporal scale of the data). Others consider that flash drought can evolve into prolonged drought. The examples analyzed here showed that many underreported yet impactful flash drought type events do not fit these definitions.

The nature of short-duration and/or rapid intensification means that flash droughts are often not identified by drought monitors using "standard" drought indices like the standardized precipitation index (SPI) and Palmer drought severity index [e.g., U.S. Drought Monitor (https://droughtmonitor.unl.edu), Brazil Drought Monitor (https://monitordesecas.ana.gov.br) and Intersucho (https://www.intersucho.cz/en)]. The temporal resolution of drought monitors, usually monthly or weekly, may be insufficient to pick up the rapid intensification. Many drought monitors do not integrate soil moisture and evapotranspiration indices, critical for flash drought detection. Therefore, stakeholders who rely on drought monitors are given short (or zero) lead times for preparation, and response may be delayed until impacts become apparent. What is more, it will be shown that the standard indices, including those purposely developed for flash drought, may be insufficiently comprehensive and flash droughts are often not identified at all. Likewise for risk assessments and decision support systems that utilize standard drought indices and methods of assessing exposure and vulnerability (e.g., Ward et al. 2020; Pulwarty and Sivakumar 2014); flash droughts may inadvertently go underdetected in monitoring systems, leading to areas and populations appearing to be at lower risk than they actually are, with consequent impacts on funding, research, adaptation, and preparation of mitigation measures. Fundamentally, flash droughts should be detected to support adaptation measures, deliver early warning, and provide emergency response (Otkin et al. 2022). Therefore, existing definitions and indices may not always be appropriate globally because they are relevant only for the regional context—climatology, soil and crop types, timing of occurrence, and other vulnerability factors concerning the local population and economic sectors. To illustrate where such events occur and how their characteristics and impacts vary, this study presents examples from around the world.

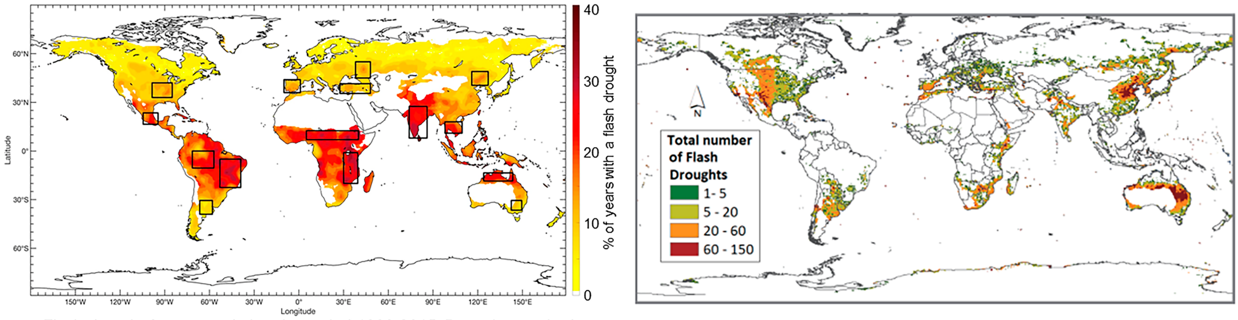
Myriad definitions were developed to aid detection in climatological studies regarding trends, probability of occurrence and climatic drivers of flash droughts, such as the identification of global hotspots and trends (e.g., Christian et al. 2021; Limones 2021; Mukherjee and Mishra 2022; Qing et al. 2022). Osman et al. (2021) discussed how the various definitions represented different stages and even different types of flash drought, and suggested the diversity of definitions should be considered a "feature rather than a bug." However, they note that trends and hotspots should be cautiously defined to avoid confusion that may arise due to capture of different aspects of flash drought. In agreement, Lisonbee et al. (2021) stated, "Given that flash drought has real relevance and implications for a wide range of resource managers, we call on flash drought researchers to be mindful that as they work to define this phenomenon they should think beyond their particular research interests to the broader societal relevance. Given the impact of flash drought on various sectors of society, this is not just a technical physical science issue." This study provides further evidence to encourage such caution. Edris et al. (2023) investigated flash drought in the United States, separating examples of "flash" drying that did not lead to drought, from flash drought, following the logic that because it is possible to have drought occur without the flash component, it is also possible to have "flash" events that never reach drought. But if that initial flash component causes impacts, even if not followed by a longer period of statistically anomalously low rainfall, then we argue that it should be considered in drought management.

Numerous flash drought hotspots and trends maps were published in recent years, based on reanalysis of climatic or



Total numbers of both heat wave and precipitation deficit flash droughts during the period 2000-2020. Detection method based on soil moisture percentile changes using modelled data. From Qing *et al.* (2022).

Multivariate flash drought indicator representing the magnitude that a region was affected by flash droughts during the period 1980-2018. Detection method based on soil moisture percentile changes using reanalysis data. From Mukherjee & Mishra (2022).



Flash drought frequency during the period 1980-2015. Detection method based on standardised evaporative stress ratio using reanalysis data. From Christian *et al.* (2021).

Total number of precipitation-deficit flash droughts during the period 1979-2020. Detection method based on drought exceedance probability index using gridded gauge-based precipitation data. From Limones (2021).

FIG. 1. Recently published examples of flash drought hotspot maps. Note the discrepancies between hotspot locations, depending on the method used for identification.

soil moisture datasets (e.g., Christian et al. 2021; Limones 2021; Mukherjee and Mishra 2022; Qing et al. 2022), or evolving flash drought conditions using near-real-time soil moisture data [e.g., Flash Drought Assessment Using SMAP Hydrology (FLASH; https://vadosezone.tamu.edu/flash/)]. It is not surprising that maps exhibit contrasting patterns (Fig. 1), given the different definitions, indicators, and datasets of differing lengths used. What those studies had in common was that there was minimal ground truthing applied to validate the hotspots and reconcile discrepancies. Our investigation took the opposite approach: we identified affected populations and discovered the hydrometeorological and other characteristics of the flash drought type events they experienced.

The aim of our study was to understand where, how, and what are the impacts of flash droughts around the world. This was inspired by the authors' knowledge of certain locally named flash drought type events underrepresented in the literature and in drought management, and their underdetection in current flash drought hotspots and trends maps. We questioned whether similar underdetected events existed worldwide; what were their unique characteristics, drivers, and impacts; and how they were reported in the literature and local media. To this end, we conducted an informal survey and followed up with a literature review to learn to what extent and how these events were being studied, catalogue their impacts, identify gaps in the research and determine the implications of those gaps. We discovered a range of flash drought types around the world, which we categorized according to their characteristics. We hereby present and discuss newly proposed flash drought types identified from observed impacts, rather than solely their climatic thresholds, in the hope of fostering further research, especially regarding how to improve flash drought understanding, mitigation and preparedness, and on societal impacts.

2. Study design

To gather examples of flash drought occurrence from around the world, we conducted an informal survey (from July 2021 to March 2022). The questions requested information on geographic region, local nomenclature, defining characteristics, drivers and impacts (see the appendix). The questionnaire was promoted across networks and on social media (Twitter, ResearchGate, and LinkedIn) aiming for global coverage. Targeted emails were sent to drought researchers identified through publications and presentations in areas of the world where we did not receive survey responses. To capitalize on relevant locally produced academic and gray literature, searches using nomenclature resulting from the survey were conducted in the local language for scientific studies, news articles, and social media posts. The local languages included Chinese, Portuguese, Hindi, Nepali, Luganda, French, Fon, and Spanish, among others. The references in the subsequent section illustrate the importance of these local language searches because often the local flash drought terms were poorly represented in the dominant English-language academic

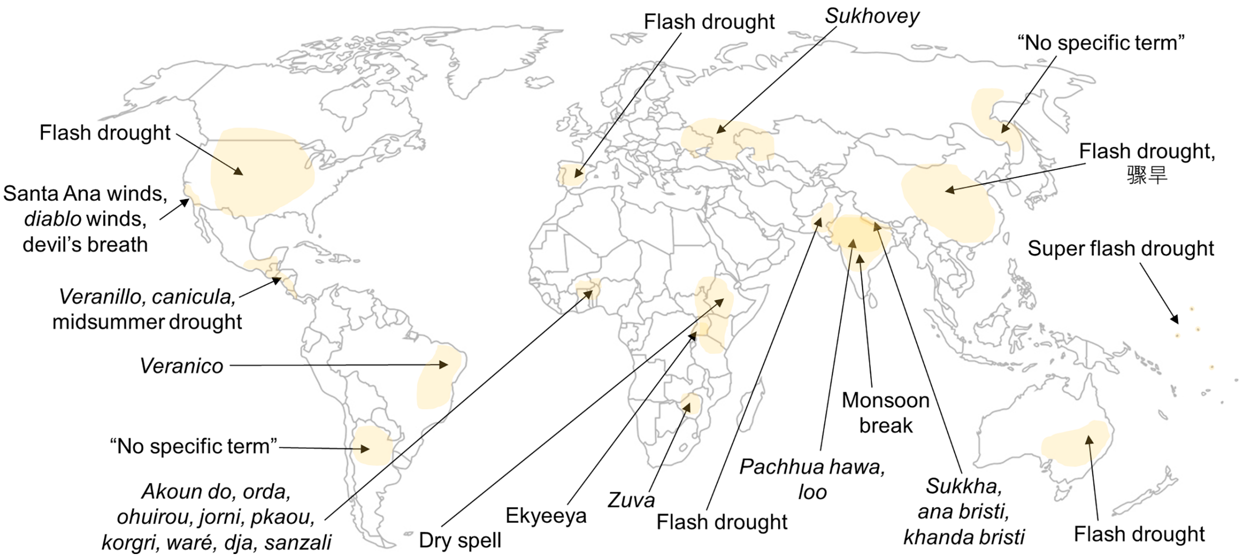


FIG. 2. Worldwide examples of flash drought occurrence with local names, based on the survey responses. The shading represents the approximate region where the identified flash droughts occur and the nomenclature is used.

literature and thus would be problematic to identify in a standard literature review. The literature review for a region stopped when we no longer unearthed any new information regarding the characteristics and impacts of the particular flash drought type, though it will be shown that only in regions like the United States and China was a wealth of literature available. Initially, the flash drought examples were divided by region, however, it became apparent that there were similarities and differences both between and within regions. Therefore, the flash drought examples were categorized according to characteristics.

3. Worldwide flash droughts

Figure 2 maps the locations of flash drought occurrence and nomenclature identified through the survey. This survey is not exhaustive, meaning blank spaces on the map may well have their own locally named and defined flash droughts. We identified 28 different names for flash droughts, representing around 30 different countries. This information resulted from around 40 survey or email respondents and includes flash drought occurrences and nomenclature already known to the coauthors (who are a deliberately invited global set of drought researchers). The study design meant the respondents were predominantly from research institutions and nongovernmental organizations (NGOs) based in or from the region for which they provided information. Where there was uncertainty in a survey response, either because the provided nomenclature had little internet presence or because the associated internet "hits" did not relate to flash drought, we cross-checked the provided information with native speakers to confirm its applicability. Subsequently, examples such as *ekyeeya* and *zuva* (see Table 1) were incorporated while two examples were excluded because they related to "normal" drought or to flash floods, respectively.

The flash droughts identified were grouped into five types according to their physical characteristics. The flash drought "types" are described and exemplified in the subsequent sections, impacts are catalogued, and future perspectives are provided. The findings from the literature review, guided by the survey responses, are synthesized in Table 1, where they are organized by location of occurrence.

a. Type 1: Flash droughts that intensify over weeks, often evolving into prolonged drought

1) CHARACTERISTICS

Type 1 consists of flash droughts conforming to the "classical" definition, that is, according to Svoboda et al. (2002): "flash drought . . . refers to rapid crop deterioration due to the adverse effects of a severe heat wave and short-term dryness, leading to a rapid onset of drought and associated impacts in agriculture, fire potential, livestock health, and other areas."

There is an ongoing debate on the precise definition of flash drought. It has been proposed that a definition must focus on rate of intensification rather than on duration because lengthy droughts lasting a year or more can originate from flash drought and short-duration droughts often do not exhibit impacts (Otkin et al. 2018, 2022). Yet the debate mostly revolves around the required rate of intensification, duration, and indicators used in identification, which can often be site specific. We classify almost all of the existing proposed definitions within this debate as type-1 flash drought. Lisonbee et al. (2021) catalogued the definitions and criteria, which typically involve onset rates measured over multiple pentads or weeks (the "flash") that must be followed by a prolonged period of dryness measuring a minimum number of pentads or weeks (the "drought"), the most common indicators being percentile changes in evapotranspiration and soil moisture. These definitions and criteria predominantly originated from the United States (e.g., Ford et al. 2015; Christian et al. 2019; Pendergrass et al. 2020) and China (e.g., Yuan et al. 2019; Li et al. 2020;

Liu et al. 2020) and match the qualitative definitions of flash drought found in the abundant and dominant flash drought literature from those countries. Parker et al. (2021) provided the first climatological characterization of flash drought across Australia, determining that flash drought often terminated as rapidly as it started or was the catalyst for long-term drought lasting many months.

2) EXAMPLES AND LITERATURE AVAILABILITY

Type-1 flash drought is categorized based on similarities in our survey and literature review of studies from the United States, China, and Australia, where the term "flash drought" is increasingly well known. The Chinese term for flash drought is "骤旱," which literally means this kind of drought occurred quickly. In ancient times, people always used "旱魃," an evil spirit causing drought, for describing drought. Any literature search using the term "flash drought" will predominantly uncover studies from the United States and China. The search term "骤旱" on the most authoritative academic database in China [Chinese National Knowledge Infrastructure (CNKI)] identifies further relevant papers published in Chinese, but the majority of flash drought research conducted in China can be found in English-language academic literature. While Australia is often discussed as a flash drought hotspot in global studies (e.g., Christian et al. 2021; Limones 2021), and despite all of the attention given to research on drought, there are few studies focused on flash drought.

3) IMPACTS

The historic legacy of flash drought research in the United States is reflected in its substantial literature concerning impacts. However, it is problematic to separate the impacts of the "flash" part of the drought from the commonly associated heat wave and subsequent prolonged drought. For example, the combination of flash drought and heat waves led to severe impacts in central and eastern regions in 1936 with over 5000 direct heat-related human deaths, crop yield reductions of 30%–80%, and significant forest fires (Hunt et al. 2020). In the central region, in 1988, drought and heat led to 10 000 human deaths and damages of tens of billions of U.S. dollars (Trenberth and Guillemot 1996). In 2011, a flash drought obliterated the spring planting season in Texas then affected ranchers due to a lack of pasture development and drying up of ponds. By autumn, widespread tree mortality and hot–dry winds caused intense wildfires (Nielsen-Gammon 2012). The widespread flash drought of 2012 resulted in agricultural losses of USD $30 billion (Otkin et al. 2018) and river-based commerce was affected, as the Mississippi River was often closed to navigation (Pendergrass et al. 2020). Seemingly, the impacts of these 2011 and 2012 events are more related to duration of drought, rather than rate of intensification. A technical report by Konrad and Knox (2017) on a 2016 flash drought centered on North Dakota stated the following: no profit was made from crop yields; water discharge reached record low levels, while restricted water release from reservoirs was greatly reduced (~35% below average), impacting hydropower generation; and wildfires were the most extensive in over 30 years, destroying thousands of structures and causing fatalities. Another rare example of in-depth investigation into flash drought impacts came from the northern Great Plains region in 2017. In addition to the usual reported impacts, such as widespread wildfires and poor air quality, Hoell et al. (2020) highlighted less commonly reported impacts: farmers had their mental health affected by stress and financial or legal pressures; other health impacts were due to excessive smoke, especially affecting people on Native American reservations and livestock; ecosystem damage was particularly felt on tribal lands, where drought impacted cultural resources such as medicinal plants and reduced wildlife populations, impacting both subsistence hunting and tribal-guided hunting opportunities; tourism suffered as Montana alone lost roughly 800 000 visitors and USD $240 million in visitor spending; tourists who still visited cut their trips short due to smoke, fires, and unavailable activities.

There are few flash drought studies from China that detail impacts. Exceptions include a report by Chen (2005) concerning Jiangxi province in eastern China that experienced flash droughts during the summer of 2003, resulting in direct agricultural losses of around USD $10 million. Zhang et al. (2018) reported that a 2013 summer flash drought in southern China affected 13 provinces and over 2 million ha of cropland in Hunan and Guizhou provinces. More common from China are studies investigating flash drought impacts on carbon dynamics, such as gross primary production (GPP): Zhang et al. (2020) utilized satellite observations of ecosystem productivity and reanalysis modeling of soil moisture showing the rapid response of ecosystems to flash drought, especially in northern semiarid China, while western China showed the least resilience to flash drought with the lengthiest recovery time. Yao et al. (2022) investigated vegetation response with solar-induced chlorophyll fluorescence for a 2019 flash drought in eastern China, finding GPP losses in 40% of the study area with cropland being the most sensitive ecosystem.

The few studies from Australia mainly reported agricultural impacts, including both vegetation that was planted or modified for agriculture and natural vegetation such as native grasses and shrubs utilized for livestock grazing. A 2015 flash drought in the state of Victoria devastated pulse crops and heavily impacted wheat production with a loss of AUD $500 million in yields (Grindlay 2015; Parker et al. 2021). Nguyen et al. (2019) reported impacts felt on the ground in eastern Australia by sheep farmers who had to remove all livestock from their properties due to a rapid change from wet conditions in December 2017 to dry conditions in January 2018. Within six months, impacts were also seen on the natural landscape with dead trees creating a desert-like landscape. Impacts reported by farmers during this event were utilized to define flash drought affected areas by Nguyen et al. (2019) to confirm the effectiveness of the evaporative stress index (ESI) for greater understanding and forecasting of flash drought in Australia. Flash drought is increasingly picked up in the news media, such as Doyle (2019), reporting on the 2018 eastern Australia event, who mentioned rapidly drying pasture and shrinking farm ponds while elaborating on the science currently performed in Australia to study flash drought.

TABLE 1. Examples of worldwide flash drought occurrence, characteristics, and impacts.

Location	Local name	Defining characteristics	Drivers	Impacts	Literature availability
Type 1: flash droughts that intensify over weeks, often evolving into prolonged drought					
United States	Flash drought	Rapid increase in moisture stress over several weeks often combined with heat waves and evolving into prolonged drought	Associated with high temperatures, few clouds, large vapor pressure deficit, and strong winds	Reported impacts are generally caused by the associated heat waves and relate more to the duration rather than the rapid intensification; such impacts include human and livestock fatalities, crop losses, forest mortality and wildfires, reduced river levels creating navigation problems, reduced hydropower generation, poor water and air quality, ecosystem damage, and loss of tourism revenue	The United States has the longest history of flash drought research and consequently the greatest quantity of studies in the literature
China	Flash drought; 骤旱	Rapid decrease of soil moisture, usually with a duration of over 2 weeks	Heat-driven in spring and precipitation deficit-driven in summer; soil type controls the rate of intensification	Agricultural losses; ecosystem decline	There are numerous flash drought studies from China in international literature, in addition to studies published in Chinese in Chinese journals
Australia	Flash drought	Rapid soil moisture decline/evaporative stress increase over 2 or more weeks that prevails for at least another 2 weeks at which point it may terminate or catalyze prolonged drought; occurs in all seasons	Mainly precipitation driven, with high evaporative demand being a strong driver	Agricultural impacts due to crop losses, loss of native or planted vegetation for livestock grazing and loss of livestock; increased risk of wildfires	Flash drought studies are only now appearing in the literature, with many acknowledging it is a research gap
Type 2: short-duration flash droughts lasting from days to weeks in the wet season					
Brazil, particularly the northeast	Veranico	Short-duration (2–20 days) dry spell (consecutive days with <2 mm rainfall) during the wet season	Precipitation deficit, high evaporative demand, and poor shallow stony soils that rapidly dry out, aggravated by a reliance on rain-fed agriculture	Reductions in crop yield dependent on crop growth stage at time of occurrence, especially impactful during the pollination stage of maize; can lead to food insecurity; low humidity can cause proliferation of insects and respiratory	Few references to flash drought but many studies on veranicos, predominantly in Brazilian journals in Portuguese; most studies are related to crop yield reduction and to atmospheric controls to improve their forecastability

TABLE 1. (*Continued*)

Location	Local name	Defining characteristics	Drivers	Impacts	Literature availability
				ailments; increased risk of wildfires and deliberate illegal burning to clear land	
India	Monsoon break	Interruption of the monsoon lasting from days to weeks with much-reduced rainfall	Lack of rainfall causes air temperature to rise, which rapidly depletes soil moisture	Reduction in yield of rain-fed kharif crops sown as the monsoon arrives (e.g., rice and cotton); yield and perishability of fruits impacted by dry spells in the harvest period	Studies referring to flash droughts are only now appearing in the literature, but there are abundant published studies on monsoon breaks
Nepal	Sukkha, ana bristi, and khanda bristi	Dry spell lasting from a week to a month that delays or interrupts the monsoon season; may be very localized	Increasingly erratic precipitation patterns with higher-intensity rainfall but fewer rainy days causing more frequent and longer dry spells; combined with increasing temperatures, this leads to reduced soil moisture	Shifting crop-growing seasons, especially summer rice (delayed by a month); reduction in crop yield; more intense rain predominantly partitions to runoff and thus recharge is reduced and springs that are used for domestic supply dry up; this groundwater drought also affects winter crop yield because of a lack of water for irrigation	Few references to flash drought, sukkha, ana bristi or khanda bristi in the literature
Ethiopia (also reported in the wider East Africa region)	Dry spell	Short-duration dry spell (3–30 consecutive days of approximately zero rainfall) during the wet season; particularly impactful when it causes “false start” or early cessation of growing season	Precipitation deficit and increased temperature creating high evaporative demand; exacerbated by widespread land degradation resulting in rapidly drying poor shallow stony soils in addition to reliance on rain-fed agriculture	Reduction in crop yield dependent on the growth stage of crops at the time of occurrence, which may result in food insecurity and loss of export earnings; in extreme cases, it can cause famine	Few references to flash drought but abundant local-to-national-scale studies on climatology of dry spells and mitigating agricultural practices
Uganda	Ekyeeya	Dry spell at wet-season onset that delays and shortens the growing season	Precipitation deficit usually associated with high temperatures; exacerbated by a reliance on rain-fed agriculture	Delays planting or leads to stunting or failure of early planted crops, ultimately causing reduced yield and food insecurity; in extreme cases, it can cause famine	Few references to flash drought or ekyeeya in the literature, but ekyeeya appears in local-language online news media

TABLE 1. (*Continued*)

Location	Local name	Defining characteristics	Drivers	Impacts	Literature availability
Benin, Burkina Faso, and Ghana	Numerous names according to the local dialect, e.g., akoun do, orda, ohuirou, jorni, pkaou, korgri, waré, dja, and sanzali	Dry spell commonly at wet-season onset where it may cause a "false start" to the growing season; begins with a warm and dry air mass followed by an increase in temperature and then no rain for days–weeks	Precipitation deficit and high evapotranspiration at unexpected times when crops are most sensitive; exacerbated by unfavorable soil properties, reliance on rain-fed agriculture, and limited stock of seed resources (for replanting)	"False start" means seeds are unable to germinate, requiring (if possible) resowing; during the most sensitive "flowering" stage of crop development, the level of stress depends on the duration of the dry spell; in extreme scenarios, there is complete crop failure	Few references to flash drought and rare mentions of the identified local nomenclature, but many region-specific studies on climatology of dry spells
Zimbabwe	Zuva	One-month hot–dry spell during the wet season	Precipitation deficit and high temperature creating high evaporative demand; exacerbated by a lack of supplemental irrigation	If occurrence is during critical rain-fed crop growth stages, then yield is significantly reduced; especially impactful during the pollination stage of maize	Few references to flash drought or zuva in the literature, and problematic to identify in online searches because of other uses ("sun")
Type 3: mid-wet-season flash droughts related to a bimodal rainfall distribution					
Central America and Mexico	Veranillo, canicula, and midsummer drought	Part of the annual precipitation cycle when there is a period of reduced rainfall in July–August that occurs between wet-season rainfall maxima	Reduced rainfall and increased temperature causing high evaporative demand; exacerbated by inadequate land use and reliance on rain-fed agriculture	Reductions in crop yield exacerbated by increased pests, disease, and production costs; can lead to food insecurity, child malnutrition, heightened inequality, and migration; national economic impacts of reduced hydropower generation and coffee production	Few references to flash drought, but country-specific, mostly climatological, veranillo and canicula studies are available in Spanish, or in English using "midsummer drought"
Type 4: short-duration flash droughts lasting from days to weeks driven by dry winds					
Southeast Europe and central Asia (also reported elsewhere in the world)	Sukhovey[a]	Hot and dry wind in spring–summer that rapidly desiccates vegetation in days	Hot air with low humidity and increased wind speed, leading to high vapor pressure deficit	Crop losses from vegetation desiccation, leaf burn, and pollen sterilization	Few references to flash drought, but plentiful agricultural studies on sukhovei in Russian and some in English
India	Pachhua hawa; loo	Hot or cold dry wind occurring at any time of year lasting from days to weeks that causes rapid soil moisture decline	Westerly dry wind from the Thar Desert	Reduced yield of, in particular, rabi (winter) crops (e.g., wheat and barley); frequent irrigation to mitigate the impact is driving	Pacchua hawa most commonly appears in local news and social media in Hindi; loo is more common in the literature in

TABLE 1. (*Continued*)

Location	Local name	Defining characteristics	Drivers	Impacts	Literature availability
				groundwater depletion; impacts are often more related to the extreme hot or cold temperatures, such as human and animal fatalities, fires, poor air quality, and disrupted transportation	meteorological and health studies
California (also reported elsewhere in the world)	Santa Ana winds, diablo winds, and devil's breath	Hot dry offshore wind in autumn–winter that rapidly desiccates vegetation	Katabatic wind from the inland deserts and mountains	Fans and spreads wildfires; psychological effects	Abundant literature relating to climatology and wildfires
Type 5: human-induced flash drought					
Low-lying SIDS[b]	Super flash drought[c]	Thin freshwater lens is depleted by extraction and evaporation while the underlying saline groundwater is drawn up	Precipitation deficit and high temperature but primarily due to poor groundwater management	Sudden (~overnight) loss of available freshwater resources	Few references to flash drought in the literature
Ephemeral sand rivers in various parts of semiarid Africa and India	—	Drop in the water table as aquifer material is removed, often to levels where it becomes problematic to extract	Sand mining, often conducted illegally, can remove significant quantities of the aquifer literally overnight; crystalline geology common to these river systems restricts alternative water sources	Sudden (~overnight) loss of accessible and available freshwater resources	Some academic studies, but mostly online local news articles on sand mining and its associated impacts

[a] The plural is *sukhovei*.

[b] Low-lying small island developing states (SIDS); see https://www.un.org/ohrlls/content/small-island-developing-states.

[c] This is the only example in the table that resulted solely from literature review.

4) PERSPECTIVES

There has been plentiful research in the United States and China on hotspots and trends. Christian et al. (2019) reported a higher frequency of flash drought events in May–June in the western United States and in July–August farther east. They also found that antecedent dry conditions increased flash drought risk for all regions and that fewer than half of all flash droughts persisted to hydrological drought. Leeper et al. (2022) analyzed 20 years of U.S. Drought Monitor data and found that drought comes and goes more frequently in the eastern United States and tends to linger in the arid western states; the characteristics of the eastern United States make it more prone to flash drought, though less prone to long-lasting drought. Osman et al. (2021) reported different hotspots across the United States depending on which definition and identification method were applied (all of which we categorize as type 1). They found that, while the frequency of occurrence did not appear to be increasing, the area affected was increasing, which was most apparent with identification methods that utilize air temperature, and thus this increase was attributed to global heating.

Wang et al. (2016) studied the long-term variations of flash drought in China, finding that the frequency increased 109% from 1979 to 2010, likely related to long-term warming driving increased evapotranspiration and decreased soil moisture. The probability of occurrence was reportedly highest in humid and semihumid regions, that is, south and northeast China. Yuan et al. (2019) similarly found that anthropogenic climate change accounted for most of the upward trend in frequency while population increase enhanced the exposure risk of flash drought, especially in southern humid regions. Liu et al. (2021), using soil moisture reanalysis products, noted significant spatial discrepancy in flash drought intensification, with soil moisture declining much faster in southeast China than in the northwest. Zhang et al. (2018) analyzed the spatiotemporal distribution of flash droughts occurring from 1983 to 2015 finding that high-temperature flash drought occurrence had increased dramatically, and northeast China was identified as a vulnerable area, indicated by more events and with longer durations. Flash droughts in China were found to concentrate in spring (high temperature) and summer (precipitation deficit). Yang et al. (2020) studied the frequency of flash droughts and of simultaneous occurrence of flash and longer-term droughts (occurring together in up to 15% of cases) while Zhu et al. (2021) reported that it is problematic to try and isolate the different drought types. The importance of soil type on impact was demonstrated by Cai et al. (2021) who revealed spatial heterogeneity of response. Areas with less vulnerable soil types, that is, higher water-holding capacity, only experienced flash droughts in the summer, while areas with more vulnerable soils were seen to additionally experience smaller spring and autumn events.

b. Type 2: Short-duration flash droughts lasting from days to weeks in the wet season

1) CHARACTERISTICS

Type 2 consists of flash droughts that develop within days and may endure only for a few more days or a few weeks. This type of flash drought occurs in regions with distinct wet and dry seasons (i.e., the tropics), representing an unexpected and short period of very low rainfall, generally accompanied by high temperature, during the normally predictably wet season.

This is a potentially controversial flash drought type because it does not conform to the majority of published definitions. Most definitions and identification methods measure a rate of intensification over a minimum number of pentads or weeks and a subsequent dry period lasting a further minimum number of pentads or weeks (see Lisonbee et al. 2021). However, our type-2 flash drought can come and go within a single pentad. Literature for some regions may consider this type-2 flash drought simply as a dry spell. Yet the precipitation deficit and accompanying heat leads to rapid depletion of soil moisture with consequent agricultural and socioeconomic impacts comparable to longer droughts. Their frequent and impactful occurrence means these events are commonly an integral part of the local culture with their own local nomenclature. Therefore, this type of event, whether it should be called a flash drought, warrants attention.

The mismatch between published flash drought definitions and our type-2 flash drought is probably because none of those definitions originated from the tropics. When we evaluated the survey responses and subsequent literature review of studies from tropical regions, it was apparent that there was a common, similar, and impactful type of event, though with regional variations. Case studies from Brazil; East, southern, and West Africa; and India and Nepal exemplify the type-2 flash drought.

2) EXAMPLES AND LITERATURE AVAILABILITY

Veranicos, translated from Portuguese as "little summers," are dry spells occurring during semiarid Northeast Brazil's wet season (February–May) that rapidly develop into agricultural drought. They are driven by precipitation deficit and high evaporative demand (average daily high temperature of ~33°C), though two other factors are of high importance, related to the crystalline geology. First, soils are poor, stony, and thin (~0.5 m), this low water capacity means they lose moisture very quickly–in a matter of days (Sun et al. 2007). Second, smallholder farmers and rain-fed agriculture account for over 90% of farmed land with low availability of supplemental irrigation (Rocha et al. 2020). Most authors consider veranicos to be 2–20 consecutive days with rainfall of <2 mm day^{-1}, considering particular crop water requirements, although some apply < 5 mm day^{-1} (Sun et al. 2007; Menezes et al. 2010; Magalhães and Glantz 1992). A literature search with search terms "flash drought" AND "Brazil" identified very few relevant papers, while searching for "veranico" AND "Brazil" identified a substantial quantity of literature, the majority published in Portuguese. Most literature focuses on impacts of veranicos on crop yields and/or atmospheric controls of veranicos to improve their forecastability.

Ethiopia is often associated with devastating drought impacts, and commonly these are driven by dry spells at inopportune times (Seleshi and Camberlin 2006). These are particularly impactful since rain-fed agriculture is dominant, providing direct livelihood for about 83% of the population and contributing around 87% of export earnings (Lemma et al. 2016). The famines of the 1970s and 1980s for which Ethiopia was synonymous were caused by delayed wet season onset and early cessation, both of which may be caused by lengthy dry spells early and late in the wet season (Segele and Lamb 2005). However, the importance of confounding factors cannot be underestimated, such as conflict, land tenure, poverty, and long-term environmental change (Bewket and Conway 2007), in particular, deteriorating fertility of agricultural lands caused by deforestation and land degradation creating shallow soils ($<$0.5 m) with poor water-holding capacity (Araya and Stroosnijder 2011). A literature search for "flash drought" AND Ethiopia revealed zero publications. However, switching "flash drought" for "dry spell" uncovered a wealth of climatological and agricultural studies. Definitions of dry spells in Ethiopia involve rainfall thresholds ranging from <0.1 to <3 mm day^{-1} and minimum durations of 2–3 days (Segele and Lamb 2005; Ademe et al. 2020). Our discussions with Ethiopian researchers from various parts of the country did not identify local terminology for dry spells.

Exploration of literature from the wider East Africa region uncovered studies with similar findings on dry spells to Ethiopia, indicating the broader applicability of that research. For instance, Barron et al. (2003) showed the significance of soil type and dry spell timing on maize yield in Kenya and Tanzania. Ajak (2018) noted the increased vulnerability to dry spells in South Sudan caused by erosion reducing soil's capacity to absorb water and the simultaneous "burning" of crops due to intense solar radiation. Although "dry spell" is commonly used across much of the African continent, local terms also exist. *Ekyeeya* is the term used to describe an early season dry spell usually associated with high temperatures in the Buganda region of Uganda. "Ekyeeya" did not show up in literature searches other than local-language news videos. *Zuva* translates as "sun" in Zimbabwe, but the term is also used to describe monthlong hot–dry spells that occur during the growing season. "Zuva" was not found in academic literature, and online searches were problematic because "Zuva" is commonly incorporated into people's and companies' names. Mutasa (2010) noted that the vernacular Shona term *kwakaita zuva* ("there was too much sun") was used to identify long dry spells contributing to crop failure.

Drought analysis has received special attention in West Africa, since the region experienced a prolonged drought in the 1970s and 1980s (Biasutti 2019; Lebel and Ali 2009), leading to humanitarian crises in the Sahel and neighboring water-scarce subregions, affecting millions of people (Hulme 2001). The West African agricultural system remains more than 95% rain fed, employing more than 60% of the workforce (Allen et al. 2018). Flash drought has different names in local communities, but generally literally translates as "water scarcity" or "lack of water due to the rain not falling," or is called the "little dry season during the rainy season." Dry spells are known as *akoun do* and *orda*, respectively, in the south and center of Benin. In the north of Benin and Ghana and in Burkina Faso, where dry spells have a more devastating impact due to a unimodal regime with relatively less annual rainfall and no alternatives for supplemental water, the name has greater variation, but refers to the same situation of water scarcity: *ohuirou*, *jorni*, *pkaou*, *korgri*, *waré*, *dja*, or *sanzali* according to local dialects. Its onset is characterized by warm and dry air masses, followed by an increase in temperature, then the rain stops for days to weeks. Abundant studies assessed dry spell occurrence and effects on crop development, without specifically referring to flash drought. Froidurot and Diedhiou (2017) observed that the region is more exposed to short dry spells (<6 days occurring up to 10 times per year) than longer dry spells, and they dominantly occur at wet season onset (April/May) inducing "false start." The occurrence and unpredictability of such events complicates smallholder farm management (Salack et al. 2020).

In India and Nepal, few studies exist concerning flash droughts, but monsoon breaks have been extensively researched and their impacts on agriculture are well documented. Because Nepal is located at the northern limit of the South Asian monsoon system, the summer monsoon (June to September) is relatively short; however, in comparison with India, the consequently longer dry season still receives 20%–40% of annual precipitation (Wang et al. 2013; Aryal et al. 2018). Therefore, Nepal is sensitive to rainfall interruptions in both the main growing season and during winter because rain-fed crops are also grown in this period. Despite annual rainfall totals remaining consistent, the rainfall pattern is becoming more erratic and intense with fewer rainy days and longer dry spells (Prajapati et al. 2021). Several terms were identified for dry spells with varying usage around Nepal, including *sukkha*, or dry condition, *ana bristi*, referring to scarcity of rain, and *khanda bristi*, meaning heterogenous summer rain, all of which are known by farmers to reduce crop yield. Neither "flash drought" nor any of these local terms are present in literature about Nepal (other than *sukkha* being the name of a drought-tolerant rice variety), and "flash drought" is just beginning to appear in literature from India.

3) IMPACTS

Unlike type 1, reports on type-2 flash drought impacts from specific events are sparse. When reported, there is often uncertainty whether the impacts were due to lengthy periods of reduced rainfall or were caused/aggravated by severe dry spells.

The longer that a type-2 flash drought persists, the greater the impact will be, but the timing is crucial. Dry spells at wet season onset cause the phenomenon of the "false start," when seeds are unable to germinate, which is especially impactful in West Africa because the stock of seeds for replanting is limited for smallholder farmers (Marteau et al. 2011; Ati et al. 2002). In Ethiopia, long-cycle high-yield crops such as maize and sorghum are planted in March (during *belg* "small/short rains"), consequently, dry spells during belg restrict crop development due to "false starts" because seeds are sown in dry soil with the expectation of rain. A specific example includes ekyeeya in Uganda in 2022 that delayed wet season onset leading to delays in planting and stunted or failed early planted crops, ultimately causing famine (Famine Early Warning Systems Network 2022). In Nepal, the rice crop is particularly affected because planting commences when the rains first appear and dry spells at this time essentially delay the monsoon (Adhikari 2018). Adhikari (2018) showed that 7 of the 10 most impactful droughts (in terms of tonnage of crop losses) that occurred in Nepal since 1972 were the result of late monsoon onset, relating to unfortunately timed dry spells.

Veranicos in Brazil are particularly impactful when they occur during the maize pollination, or silking, stage (likewise reported for zuva in Zimbabwe) resulting in yield reductions of 20% for a veranico lasting only 3 days and around 50% for veranicos persisting for 5–11 days (de Carvalho et al. 2000). If veranicos occur during the earlier and longer (thus they are more likely to occur) vegetative stage, there is a reduction in plant growth with decreases in leaf area and biomass, thus reducing maize yield for silage (Bergamaschi et al. 2006). While maize is the dominant rain-fed crop in Northeast Brazil, representing 50%–80% of agricultural production (Sun et al. 2007; Rocha et al. 2020), other studies reported yield impacts from veranicos on other crops, including rain-fed beans, cowpea and sugarcane, and irrigated rice, banana and cotton (Menezes et al. 2010; Magalhães and Glantz 1992; Anderson et al. 2016). Similarly in India, crop sowing commences in June when the monsoon arrives. These *kharif* crops are extremely sensitive to rainfall in June and July due to high water requirements in early stages required for their growth and development, particularly for rice. In recent years, there has been a change in monsoon patterns; strong premonsoon and early monsoon rains are followed by a monsoon break in July (Kumar 2021; Saini and Das 2021). Strong premonsoon showers lure farmers into planting crops over larger areas, but subsequent monsoon breaks damage crops in their growth phase, resulting in significant losses (Sengupta et al. 2017). Substantial damage to different kharif crops was reported by farmers in various parts of the country due to monsoon breaks in the early growth stage; examples include rice in Nagaland (Jamir 2021) and Odisha (Mohanty 2021), soybean and cotton in Maharashtra (Deshpande 2019; Sengupta et al. 2017), and cotton and chili peppers in Telangana (Lasania 2018).

Dry spells during the main *kiremt* wet season in Ethiopia impact short-cycle crops like *teff*, barley, and vegetables. Araya and Stroosnijder (2011) reported that dry spells of ~10 days were among the major causes of crop failure in rainfed farming systems; indicating that 8%–40% of crop failure in the drought-prone north was due to dry spells during the growing season. This is similarly reported in West Africa when the crop experiences water stresses causing loss of flowers, yellowing of leaves, decline in development rate, reduction in yield, and, in extreme scenarios, complete crop failure (Sultan et al. 2005; Vanuytrecht et al. 2014). Regmi (2007) reported that drought caused a reduction in rice production of 27%–39% in eastern Nepal in 2006 relative to 2005, referring to specific months that received significantly reduced rainfall when other months were normal. Consultations by Regmi (2007) with communities around Nepal revealed that the increasingly inconsistent rainfall pattern led to the usual peak monsoon months of July/August when people used to have to deal with excess water now often being periods of moisture stress. The effects are exacerbated since many poor households switched to high-value monoculture crops such as cardamom or fruit in a bid to bring in more income (Nepal Climate Vulnerability Study Team 2009).

Reported for India but likely valid for other regions: while cereals and seed crops are highly sensitive to rainfall in the crop growth stages, fruit crops are more sensitive to rains during harvest. Rainfall variability in the harvest period significantly affects the quality of the fruits in terms of color and taste; dry spells result in premature ripening and lower shelf life of the fruits (Bisht 2022). The yields of apples grown in Himalayan regions such as Kashmir have been found to be adversely affected by dry spells in the harvest period (Hassan 2021) and the yields of oranges grown in Maharashtra were significantly reduced in 2017 because of a harvest-time dry spell (Madaan 2017).

Nonagricultural impacts of type-2 flash droughts include abnormally low humidity associated with veranicos causing respiratory ailments brought on by enhanced airborne particulate matter and proliferation of insects (Jardim 2012). Satyamurty and Padilha (2006) reported that unscrupulous farmers farther west in Brazil capitalize on the dry combustible conditions created by veranicos to burn tropical forest and savannah to expand their farms. Poonia et al. (2022) analyzed the impacts of flash droughts on terrestrial ecosystems in India using remote sensing derived GPP and found that ecosystems in the Ganga Basin were the most vulnerable to flash droughts. However, their results are somewhat contradictory to those of Mahto and Mishra (2020), as Poonia et al. (2022) found that flash droughts dominantly occur in the nonmonsoon season. This discrepancy could be due to the difference in soil moisture datasets used in the two studies, variable infiltration capacity (VIC) model versus reanalysis products, highlighting the challenges in flash drought analysis and raising concerns about which indicators are capable of capturing the reality on the ground. An interrelated impact of dry spells in Nepal from increasingly erratic weather is caused by the corresponding higher intensity rainfall. This rainfall predominantly partitions to runoff, so reduced recharge leads to groundwater drought where springs are relied upon by 80% of the 13 million people living in Nepal's mountains and hills (Taylor 2019).

4) PERSPECTIVES

Reis et al. (2011) found no increase over time in frequency or duration of veranicos and no relationship to rainfall totals. Guerreiro et al. (2013), on the other hand, demonstrated an increasing trend in quantity of dry days though only during the early growing season; essentially, the dry season is getting drier. de Andrade et al. (2016) similarly reported no relationship between veranico occurrence and annual rainfall with locations reporting higher than average annual rainfall also experiencing damaging veranicos and homogenous rainfall zones heterogeneously experiencing veranicos. Seleshi and Camberlin (2006) revealed that, in Ethiopia, kiremt dry spell length averaged from 3 days in the west to 20 days in the more arid east, while belg dry spells averaged from 10 to 31 days. The study found no trends in duration or frequency in accordance with Bewket and Conway (2007) and Kebede et al. (2017) among others, despite trends in total annual rainfall. Bekele et al. (2017) showed that the probability of occurrence is highest during the belg–kiremt transition (~June), followed by during belg, then toward the end of kiremt. Ademe et al. (2020) similarly found that, for example in the Central Rift Valley, there was a 26% chance of experiencing kiremt dry spells longer than 7 days at the early growth stage of a crop and the probability reaches 92% during the late development stage. In India, Rajeevan et al. (2010) found that the number of monsoon breaks had a significant negative correlation with the total monsoon season rainfall, implying that drought years are expected to have a larger number of dry spells. Therefore, if flash droughts (as defined by Mahto and Mishra 2020) dominantly occur during monsoon breaks, it is likely that flash droughts coincide with monsoon drought years. Indeed, three of the top four most intense flash droughts identified by Mahto and Mishra (2020), in 1979, 1986, and 2001, were also major monsoon drought years. We note that Lisonbee et al. (2022), in conceptual agreement with Mahto and Mishra (2020), considered that flash droughts defined by rapid soil moisture loss in northern Australia transpired only in *some* monsoon breaks/wet season false starts, which occurred on average in 20%–30% of wet seasons from 1950 to 2020.

Unlike for other types, research on type-2 flash droughts commonly offers mitigation strategies. Following false starts, resowing is an option, but that necessitates having available seeds, and the growing period will be shorter (Marteau et al. 2011). Supplemental irrigation during crop establishment would mitigate early dry spells, but there is commonly a lack of water availability at the end of the dry season. Therefore, Araya and Stroosnijder (2011) recommended delaying sowing until after the soil has received enough moisture then providing supplemental irrigation should dry spells occur later in the growing season when water reserves have accumulated. Several studies investigated the impacts of dry spells in certain areas on specific crops, such as maize (Mamo et al. 2016), sorghum (Tamiru et al. 2015), and chickpea (Lemma et al. 2016), typically giving recommendations of when to sow to avoid simultaneous occurrence of critical growth stages (when crop water requirement is highest) with the highest probability of dry spells. There are recommended soil preparation techniques (e.g., subsoiling and ridge tillage) to mitigate dry spells in degraded soils (e.g., McHugh et al. 2007; Mamo et al. 2016).

c. Type 3: Mid-wet-season flash droughts related to a bimodal rainfall distribution

1) CHARACTERISTICS

Type 3 is flash drought that occurs in the middle of the wet season in regions that have two distinct rainfall maxima. The timing is predictable, but not all years and all areas experience a sufficient reduction in rainfall between maxima for drought conditions to arise. Many examples in the type-2 section have a bimodal rainfall distribution, that is, the “small rains” and “big rains” experienced in much of Africa. However, the events referred to in this section specifically relate to the lull in rainfall between peaks.

2) EXAMPLES AND LITERATURE AVAILABILITY

Veranillos share the same translation from Spanish as veranicos from the Portuguese for “little summers.” However, apart from similarly occurring during the wet season, their characteristics are different. Veranillos are part of the annual precipitation cycle in Central America and southern Mexico during the period of reduced rainfall in July–August between rainfall maxima (Magaña et al. 1999; Verbist et al. 2018). The alternative name, *canicula*, alludes to the corresponding higher temperatures equivalent to “dog days,” referring to hot sultry weather in the Northern Hemisphere summer. While not unknown in the western Caribbean, veranillos predominantly occur on the Pacific side of the Central American isthmus, particularly impacting subsistence farmers of the “dry corridor” (Verbist et al. 2018). Veranillos, or caniculas, are varyingly impactful and classified according to 1) duration, the time between rainfall maxima—10 to 100 days depending on location, and 2) their magnitude or intensity, the average daily rainfall between maxima—5 to 25 mm day^{-1}, the daily rainfall minima is rarely zero (Alfaro 2014; Anderson et al. 2019; Carvajal Montoya 2014). A literature search with search terms “flash drought” AND “[any country in Central America, or Mexico]” identifies very few relevant papers. However, using “veranillo” or “canicula” identifies a greater number of studies, many of which are subregion specific and published in Spanish. Most studies are climatological and when published in English commonly use the term “midsummer drought.”

3) IMPACTS

Given the prevalence of rain-fed agriculture in the region, crops are directly impacted (Magaña et al. 1999); agricultural and hydropower impacts are often mentioned in scientific articles, but few detail socioeconomic impacts. However, gray literature exists describing impacts of particular events in Central America and Mexico. The Comisión Económica para América Latina y El Caribe (2002), referring to the 2001 veranillo, reported USD $13 million spent on emergency food aid, USD $15 million losses in industrial production, and proposed actions to limit future impacts. In 2014, the usual 2–3-week veranillo persisted for 8–10 weeks: Flores Mora (2014) provided statistics and anecdotes of food insecurity while Echeverría (2016) provided economic losses in different sectors, such as agricultural losses of USD $465 million and of hydropower totaling USD $186 million. Reductions in crop yield are often exacerbated by increased pests and disease, and by increased production costs (Carvajal Montoya 2014). Food insecurity and child malnutrition have required humanitarian aid, such as for 3.5 million people across Guatemala, El Salvador, and Honduras in 2016; women and children are disproportionately impacted, heightening inequality (Verbist et al. 2018). Hunger brought on by drought-induced food insecurity is considered the principal driver of migration to urban areas, Mexico, and the United States (Entremundos 2017).

4) PERSPECTIVES

Veranillos are projected to increase in intensity and occur earlier due to climate change thus driving the projected drying of Central America (Rauscher et al. 2008), though there is substantial variability within the region (Anderson et al. 2019). This trend may lead to reclassification of type-3 flash drought because the most impactful aforementioned veranillos followed failed spring rains (FAO 2019).

d. Type 4: Short-duration flash droughts lasting from days to weeks driven by dry winds

1) CHARACTERISTICS

Type 4 is flash drought caused by dry winds, which can have extremely rapid onset—measured in hours to days—and last as long as the winds remain, although with drought conditions potentially prevailing for weeks.

2) EXAMPLES, LITERATURE AVAILABILITY, IMPACTS AND PERSPECTIVES

Pachhua hawa, westerly winds blowing over northern India, lead to flash moisture decline and premature drying of crops. While they are well-known and well-discussed phenomena in the region, reflected by abundant local language news articles, there is scant reference to pacchua hawa in academic literature. Pachhua hawa comes from the Thar Desert, and hence it is very arid; upon reaching the Ganga Basin it rapidly depletes soil moisture (Amar Ujala Bureau 2017). Summer winds, known as *loo*, are strongest in May–June, and are gusty, dusty, dry and extremely hot, 45°–50°C (Rana 2007). There is risk of heatstroke for humans and animals, widespread browning of crops, and evaporation of ponds, which can beneficially result in reduced malaria levels (Singh 2010). There is increased fire risk for both fields and homes; further exacerbated by the propensity for cooking on coal, wood and straw fires that easily generate sparks (Shaktilochan 2021). These events are unpredictable (due to local factors affecting stochasticity) and rarely endure; stronger winds persist only for days to weeks though light winds may continue. Pachhua hawa may happen throughout the year thus can affect any stage of crop growth though the impact is different. *Rabi* (winter) crops such as wheat and barley experience the most severe impacts when the quality and weight of kernels decreases significantly (Jagran 2022). To mitigate pachhua hawa, frequent irrigation is conducted during these periods, which depletes groundwater resources (Amar Ujala Bureau 2017; Dangar and Mishra 2021). While summer winds are accompanied by heat waves, winter winds are accompanied by cold waves. In winter, fruit production is highly susceptible to the low temperatures and natural vegetation suffers as people cut down trees to burn in an effort to keep warm, the resulting smoke adversely affects transportation; human deaths related to the cold can number in the hundreds (Samra et al. 2003; Mahdi et al. 2015). However, as per the relationship with type-1 flash drought and heat waves, the impacts of cold waves are predominantly caused by low temperature rather than rapid drying characteristic of flash drought. Additionally, these winds may delay the onset of rainfall by obstructing the flow of moisture-laden easterly winds. In 2021, such blocking led to a 43.5% reduction in total monsoon precipitation in northern Rajasthan causing crop losses (Samachar Nama 2021).

Sukhovei are hot–dry winds that can desiccate vegetation and sterilize pollen in days (Lydolph 1964; Semenova and Slizhe 2020). This climatic feature occurs in spring–summer in Ukraine, southern Russia and Kazakhstan, all important grain production areas; consequently, the Soviet Union held conferences on sukhovei given their threat to agriculture (Lydolph 1964). Indeed, much of the literature on sukhovei was published during Soviet times in Russian. The air masses may originate from Middle Eastern and Central Asian deserts or, as is more generally considered, are local weather transformations. The hot (>25°C) and dry (relative humidity $< 30\%$) winds usually last for 2–4 days, but extreme events span 2–3 weeks (Buchinskij 1970). Semenova and Slizhe (2020) reported that 1-day sukhovei occurred in Ukraine in 90% of years and lasted 2–4 days in 30%–35% of cases. Sukhovei intensity is categorized according to rapidity of temperature rise and relative humidity decrease, wind speed, and corresponding vapor pressure deficit; the most extreme category results in leaves burning (turning yellow or brown) in under an hour (Lydolph 1964).

During our literature review of sukhovei, we found reports of such winds in grain-growing areas of China, United States, Australia, and South Africa (Lydolph and Williams 1982; Motha and Heddinghaus 1986; Tavakol et al. 2020; Kang et al. 2022); some authors noting that sukhovei was the correct term to apply globally to such winds. Impacts similarly involve crops wilting, premature ripening, and ultimately reduced yield. There is abundant Chinese-language literature on the impacts of "dry hot wind" on crops in China (see Kang et al. 2022). In their analysis of "hot dry windy events" in the United States, Tavakol et al. (2020) noted how they are linked to the rapid intensification of hot–dry conditions characteristic of flash droughts. A climatologically different but related event is Santa Ana winds (or *diablo* winds, or devil's breath), a hot and very dry katabatic offshore wind occurring in autumn and winter on the California coast of the United States (Duginski 2022). The gusty winds desiccate vegetation in days triggering and exacerbating wildfires (Jin et al. 2014). Traditions and anecdotes in California and elsewhere speak of how such winds affect emotions and behavior, leading to increased crime rates (Saporoschenko 2011). There are more examples of well-known dry winds around the world, which have corresponding literature reporting similar agricultural impacts and increased fire risk, such as southern Europe's *sirocco*, West Africa's *harmattan*, the Andes' *zonda*, the Middle East's *simoom*, and Taiwan's 焚風 "burning wind." These phenomena, along with sukhovei, pacchua hawa, and Santa Ana winds, differ in origin and nature but we consider them all as type-4 wind-induced flash drought. Tavakol et al. (2020) and Jin et al. (2014), among others, stated that global heating was likely to increase the frequency of hot–dry wind events.

As per type-2 flash droughts, agricultural studies provide mitigation techniques, such as irrigation, planting of shelter beds and conservation agriculture to add moisture, lower temperatures, reduce wind speed and thus decrease evapotranspiration, in addition to the provision of comprehensible and actionable weather forecasts for farmers (Lydolph 1964; Mahdi et al. 2015). At least daily computations of vapor pressure deficit can signal conditions leading to crop stress and more frequent scrutiny of crops is necessary for timely mitigating actions (Motha and Heddinghaus 1986).

e. *Type 5: Human-induced flash drought*

1) CHARACTERISTICS

Type 5 consists of flash drought driven by human actions (after "human-induced drought" from Van Loon and Van Lanen 2013). We refer to human actions that would rapidly/immediately change the hydrological system, such as depletion of water resources (e.g., through excessive groundwater extraction) and disconnection of flow paths (e.g., through extractive industries and infrastructure developments). We note that, over longer time scales, human interventions in the Earth system (e.g., greenhouse gas emissions, deforestation, and urban expansion) change local soil–water–land–atmosphere interactions, which are intensifying the occurrence and impacts of droughts, and increasing the likelihood of all types of flash droughts

(Qing et al. 2022; United Nations Convention to Combat Desertification 2022; Zhao and Dai 2022).

2) EXAMPLES, LITERATURE AVAILABILITY, IMPACTS, AND PERSPECTIVES

We identified only two examples of human-induced flash drought and acknowledge a need for further investigation. Low-lying atoll, reef, and limestone islands commonly have limited freshwater resources, and many rely on rain-fed subsistence agriculture, making them vulnerable to drought (Keener et al. 2012; United Nations Economic and Social Commission for Asia and the Pacific 2018). It would be expected that the thin highly permeable soils and thin shallow aquifers (White and Falkland 2010) could experience rapid agricultural and groundwater drought, yet we discovered only a single reference to flash drought on small island developing states (SIDS). Heim et al. (2020) reported that during droughts, wells extracting freshwater draw up the underlying saline water until the brackish transition zone replaces the freshwater lens, "there is immediately no fresh drinking water and a life-or-death crisis occurs—the people have no water, so this drought impact can occur literally overnight (a 'super flash drought')." However, White and Falkland (2010) showed that freshwater lenses can buffer multiyear droughts. They indicated that the situation described would most likely be due to poor groundwater management, such as utilizing vertical wells with too-high extraction rate rather than long horizontal infiltration galleries or skimming wells.

Ephemeral sand rivers are common throughout the world's dryland regions, often providing a water source where more conventional sources are unavailable (Walker et al. 2018). These rivers are also a source of sand, the most mined and in-demand material on Earth and central to infrastructure and economic development (Bendixen et al. 2021). Among various impacts, extracting river sands lowers the water table and reduces the quantity and accessibility of water resources. Illegal sand extraction is a growing problem, often instigated by criminal gangs who may move in and extract significant quantities of sand literally overnight, for example in southern Africa (Williams 2013), West Africa (Lawal 2011), and India (Padmalal and Maya 2014). Dryland river systems are commonly underlain by crystalline bedrock; therefore, removing the sand means removing the aquifer, and the water resource collapses.

4. Discussion

a. *Are the identified examples flash droughts or dry spells? Does it matter?*

Some readers may disagree that all of the flash drought types described here are droughts, because of their duration (many are too short-lived) and frequency (they occur with too much regularity to be an extreme event). The traditional definition of drought is based on how dry the conditions are relative to the long-term average conditions. Our survey identifies local nomenclature that is used by people to describe phenomena that have a negative impact on agriculture or ecosystems as a result of rapid drying in their respective regions. We propose that even though these events may not classify as statistically extreme events (given specific index definitions and their limitations), they are associated with drying and have significant reported impacts and therefore should also be considered in drought management. Any event that is associated with rapid drying and deterioration of vegetation health could be referred to as flash drought. This rapid drying could be caused by excessive temperatures of heat waves or lack of rainfall in a dry spell. Rockström (2003) stated that scientists and politicians were too quick to think of meteorological drought when they heard the term "drought" rather than agricultural drought, which is much more common, may be short lived or may be induced or aggravated by human actions and soil types, and is what damages crops and impacts livelihoods. Similarly, Araya and Stroosnijder (2011) pointed out, "There are many definitions of drought, but from the viewpoint of local people, drought is any season with low rainfall in relation to crop water demand that results in poor crop harvest or total crop failure and/or livestock suffering or dying because of feed shortages as a consequence of poor rainfall distribution/amount." We are comfortable with readers disagreeing that all of our types (most likely the short-duration types 2 and 4) ought not be considered flash drought, as long as it can be agreed that all these types must be considered in drought management. That is because the impacts are very similar to those of "normal" droughts and all flash drought types require similar adaptation and response measures. These measures do not change when the duration passes an arbitrary threshold of pentads, rather they are dependent on the local context. While this debate is interesting in academic circles, it should not overshadow key implications of this study:

- Rapid drying events occur around the world and people readily identify their effects.
- Irrespective of how they are classified, these events should be considered in drought research because their impacts match those of droughts.
- Despite not conforming to existing literature criteria, they must be considered in drought monitors and drought management where the aims are to plan for and mitigate drought impacts, such as crop losses and food insecurity.
- If current indices utilized in drought research and drought monitors cannot detect all these rapid drying events, then the definitions and indices require improvement.

The key unifying characteristic across the flash drought types is rapid soil moisture drought (except possibly type 5, which is hydrological drought). How quickly that occurs and the resultant impact on crops, ecosystems, livelihoods and economies, depends on various locally relevant factors described below.

b. *The significance of local nomenclature*

Evidence from the case studies suggests that when a climatic event is sufficiently impactful and recurrent it becomes part of the local culture, earning a familiar name. This sentiment was shared by Lydolph (1964) in an introduction to sukhovei: "Cold and drought are the preponderant climatic obstacles to agricultural production and comfortable living. So significant are they that outstanding occurrences have been tagged with specific names." Therefore, locations with named events should be represented on flash drought hotspots, as in Fig. 1. Ethiopia appears to be an exception with no local nomenclature even though hot–dry spells are common and damaging. This may be because climate variability is intense and inherent in Ethiopia (Bewket and Conway 2007) meaning dry spells are almost guaranteed to occur at some point in the wet season (Ademe et al. 2020; Bekele et al. 2017) or it is due to our investigative method that was unable to reach all parts and ethnicities in the region. That is in contrast to West Africa where colleagues undertaking fieldwork in multiple locations meant copious local nomenclature was identified. The lack of local nomenclature for flash droughts in places like the United States, Australia and Europe may relate to 1) the smaller proportion of people involved in agriculture who are directly affected and 2) the higher threshold of flash drought, in terms of intensity and duration, required to generate significant impacts meaning damaging events are less frequent.

c. *The importance of local context*

Whether a period of rapid drying should be considered to be a flash drought, or is even noticeable, is dependent on the resultant impacts. The time taken for impacts to reach a particular level of severity depends on a range of factors specific to the location. This implies that transferability of climate-only metrics for identification and classification of flash droughts will be limited. The interrelated location-specific factors governing severity include:

1) TIMING

As described for type-2 and type-4 flash droughts, even short-duration events can be extremely impactful if they occur at critical crop growth stages. Depending on the crop, this may be the germination, reproductive, or harvest stages. The same duration and intensity flash drought outside of critical periods has much reduced impact.

2) CROP TYPE

Evidently, the type of crop matters, for reasons such as the water demand at particular times of year and how demand relates to local climate variability and climate change. Much research exists on which crops are resilient to water and heat stress with indigenous plants or specially developed cultivars faring better (Sambo 2014; Fahad et al. 2017). For instance, rain-fed production of sorghum or millet in semiarid regions of Africa will suffer fewer losses than will nonnative maize given the same flash drought (Hadebe et al. 2017).

3) ANTECEDENT CONDITIONS

Following a period of wet weather when soil moisture and water levels are high, the intensity and duration of a flash drought must be greater for impacts to occur. This alludes to the importance of the other factors described here, especially soils and irrigation infrastructure.

4) SOILS

A soil that retains moisture requires longer extreme conditions to reach agricultural drought. Hence, Barron et al. (2003) showed significantly higher crop yield losses in East Africa in sandy soils than in clayey soils. Land degradation is consequently significant as erosion and fire reduce soil moisture holding capacity (Ajak 2018). Underlying geology is therefore an important factor, considering both soils and the availability of supplemental groundwater irrigation.

5) AVAILABILITY OF SUPPLEMENTAL IRRIGATION

While flash droughts affect cultivation around the world, the intensity and duration thresholds required to inflict severe damage are higher where irrigation is available. Antecedent conditions, timing, crop type, and soils can be less influential where there is irrigation infrastructure and water resource availability, such as groundwater, that can buffer drought. However, irrigation is clearly not a cure-all solution because we still see flash drought agricultural impacts in irrigated areas. Rapid drought onset and insufficiently timely warning and response will still lead to impacts. What is more, while Rosa (2022) advocated for irrigation as a potential climate adaptation solution to alleviate heat and water stress in crops, Jha et al. (2022) reported that irrigation has limited influence on heat stress that is often associated with flash droughts.

6) SOCIOECONOMIC FACTORS

Vulnerability is interrelated with other factors on this list, additionally incorporating socioeconomic circumstances that are critical in determining the severity of a flash drought. Subsistence rain-fed farmers and pastoralists with low capacity to cope with flash drought, for example, may suffer severely when a similar intensity event could go largely unnoticed in other regions where agriculture employs a smaller proportion of the population, irrigation is available, there is access to animal feed if pasture and forage are affected, and different governance arrangements mean the region is better prepared for droughts.

7) PREDICTABILITY

Many flash droughts identified around the world have predictable timing, whereas intensity and duration are harder to predict. Adaptation and mitigation measures can be established to lessen impacts where predictability is high. The timing of sowing and harvesting, for example, can be adjusted according to indicators of when and how severe a flash drought may be. A problem, therefore, is climate change-induced shifts of weather patterns affecting event timing, which also leads to both traditional and scientific indicators becoming unreliable (Jiri et al. 2016; Mukherjee et al. 2018).

d. *Comparison with maps of flash drought hotspots*

Many of our examples are located in areas where some of the hotspot maps in Fig. 1 indicate flash droughts should be uncommon. The map by Mukherjee and Mishra (2022) identifies few of our examples as hotspots, which is surprising given that their methodology utilizes (reanalysis) soil moisture data and that rapidly intensifying soil moisture drought unifies our types. This discrepancy could be related to flash drought identification using a minimum duration threshold of 15 days and the use of coarse-resolution global soil moisture data products that exhibit large information losses, neglecting local-scale heterogeneities of the landscape and land use (Vergopolan et al. 2022). However, that does not explain the nonidentification of the known flash drought hotspot of the central U.S. Great Plains (e.g., Chen et al. 2019). The map by Christian et al. (2021) detects all of our examples located in the tropics, with essentially almost all of the tropics labeled as flash drought hotspots. This is likely due to a methodology using an evaporative stress index such that only the summer growing season is considered in midlatitudes and the entire year in the tropics. Consequently, the flash drought count is higher in the latter because events were counted even when they occurred in the dry season. The map by Qing et al. (2022) compares very well to our examples, possibly because of a methodology that incorporates events lasting a single pentad. However, the map does not identify the hotspots of East Africa, Northeast Brazil, northern India, and large parts of China. The map by Limones (2021) does not identify all of our examples, which was expected because the methodology considers only precipitation-deficit flash droughts. Hence, parts of the United States, India, and China are marked as hotspots but Northeast Brazil, Central America, and West Africa are not.

Instead of mapping flash drought hotspots from (often arbitrary) physical definition thresholds, we propose that subsequent flash drought hotspot maps be codeveloped and validated by the populations living in those areas. This would be a promising step toward reconciling discrepancies in hotspots between maps. It is understandable that discrepancies exist due to the different definitions, detection methods and datasets utilized. This study is a first attempt, with an opposite approach to other studies, to obtain guidance from affected populations to derive definitions, in this case for different flash drought types. A single quantitative flash drought definition appears impossible, but we should aim for composite identification methods that lead to comprehensive identification and ideally to forecasting of all types of potentially impactful flash droughts to aid drought management.

e. Challenges

1) LACK OF DROUGHT-IMPACTS MONITORING

Considering type-1 flash droughts, the severity and frequency of impacts illustrates that even the United States, where flash droughts have been studied most intensively, remains vulnerable. China has also seen much flash drought research, yet there is little research on socioeconomic impacts brought by flash droughts, which limits drought management agencies' ability to prepare for and mitigate impacts. Indeed, a similarity between most of the examples is that the flash droughts are often well studied from a climatological perspective. There is plentiful literature on atmospheric controls, probabilities of occurrence, and trends of Central American/Mexican veranillos/caniculas, North American and Chinese flash droughts, monsoon breaks in the Indian subcontinent, and dry spells in Africa. However, rarely are the studies driven by the perspective of populations who experience them, nor how well these events can be predicted ahead of time. This is a significant research gap. Similarly, despite the progress in developing flash drought definitions and identification methods, little research has compared these with impacts on the ground (Otkin et al. 2022). We hope to encourage such comparisons to develop improved indices to identify flash droughts; we need impact information to reveal the thresholds when an event becomes a problem.

In fact, this is true of all types of drought. The majority of monitoring programs for "normal" droughts similarly suffer from a lack of integration of data concerning how drought is experienced (Pulwarty and Sivakumar 2014; Van Loon et al. 2016), primarily due to a global lack of drought-impact monitoring (Bouwer 2011; Ward et al. 2020). Redmond (2002) recommended that drought indicators be calibrated for relevance to impacts but acknowledged that impact data are comparatively scarce, particularly at finer spatial resolution. Bachmair et al. (2016) found that few drought indicators around the world had been calibrated with impacts. Some inventories of socioeconomic drought-impacts data exist, and there is growing interest in citizen science and crowdsourcing to contribute data in near–real time, which is particularly necessary for rapidly developing events like flash droughts (Smith et al. 2023). However, our examples showed that separating flash drought impacts from impacts due to longer periods of dryness and/or heat can be problematic, especially when considering longer flash drought types that evolve into or occur within normal droughts (Walker and Van Loon 2023).

2) NEED FOR NEW INDICES, HIGHER-FREQUENCY MONITORING, AND IMPROVED DROUGHT MONITORS

Most traditional drought indicators are based on anomalies of a particular variable with respect to its historical climatological distribution, that is, defined based on how rare a drought is relative to the climatology. This framework for defining drought is required for distinguishing droughts from long-term water scarcity. However, our survey shows that flash droughts need not be a rare event as rapid drying can be a part of the climatology of a place such as strong dry winds or breaks in monsoons. In addition, with the current intense and nonstationary changes in climate, drought-like conditions can become the new climatological normal in many places. Hence, flash drought indicators should be designed to quantify rapid declines in water availability relative to societal and ecological water demands at a particular place and time and not solely their rarity.

Traditional drought indicators such as SPI or standardized precipitation evapotranspiration index (SPEI) standardize the time series of hydroclimatic variables by essentially removing the effects of seasonality in these variables. Many of the flash drought indicators also use the same framework for standardizing changes in evaporative stress or soil moisture deficits. However, our survey shows that seasonal changes can be a cause of rapid drying events; for example, type-3 flash droughts are caused by bimodality of rainfall distribution in the wet season and type-4 flash droughts are caused by dry winds in a particular season. Hence, standardization can prevent the detection of such flash drought events, as well as reduce the action time from when drought actually happens to when it is finally detected in biweekly to monthly monitoring indices.

Furthermore, the characteristics of type-2 and type-4 flash droughts mean that common drought indices will struggle to identify them. These events can come and go within the minimum analysis period of common hydrometeorological indices or between satellite passes for remote sensing indices, and even within a pentad utilized for many flash drought indices. The lack of relationships with longer time scale (e.g., monthly or annual) rainfall totals shows that rainfall-based indices are generally inappropriate for drought risk assessment in areas of these types of flash drought, only assessment of anomalies at daily time scale may be suitable. Indeed, broader assessment in such regions based solely on rainfall totals, temperature, or normalized difference vegetation index (NDVI) may lead to misinterpretation of water availability or to poor water resource and agricultural management (Guerreiro et al. 2013; Vergopolan et al. 2021a). When dry spells hit at particular crop growth stages (e.g., flowering), cultivated fields often remain green while development of the crop itself is hampered and high losses occur; referred to in Brazil as *seca verde*, “green drought” (Menezes et al. 2015). These situations are difficult to identify with remote sensing indices like NDVI. If they are identified using NDVI, the damage is already done, without preparation time for mitigating drought impacts. Conversely, if a flash drought is estimated based on rainfall and air temperature, but there is sufficient soil moisture in the root zone for crops to tolerate the heat stress, flash drought impacts may be minimal (Vergopolan et al. 2021a). The critical scenario is, therefore, when flash drought conditions generate meaningful impacts yet are underdetected and drought responses are not launched, negatively impacting crop yield and farmer livelihoods.

As drought monitors and drought management authorities are becoming more widespread throughout the world (Smith et al. 2023), it appears imperative to ensure that all types of flash droughts are incorporated and able to be identified. In addition to the integration of impacts data, newly developed indices need to be location-specific (considering the locally important factors described above) for improvement of drought monitors. Rapid intensification indicates a need for high frequency, at least daily, monitoring. Chen et al. (2019) recommended closely monitoring rapid changes in evapotranspiration, along with soil moisture and precipitation conditions, to provide early warnings of flash drought development. Ford et al. (2015) demonstrated the utility of soil-moisture-based early warnings as they consistently preceded U.S. Drought Monitor drought classifications by 2–3 weeks for flash droughts. The spatiotemporal scales of drought monitors must be relevant to the events experienced in the region and timely for the actions triggered by the drought monitors.

3) IMPROVED FLASH DROUGHT FORECASTING

For the forecastability of type-1 flash droughts around the world, Chen et al. (2019) reported that flash drought predominantly occurred in the central United States, during warm seasons, and is largely correlated with La Niña episodes. Zhang et al. (2019) analyzed high-temperature flash droughts in southern China and similarly found that La Niña episodes triggered a higher risk of flash drought and noting a relationship with El Niño Modoki. A study by Nguyen et al. (2021) focused on the 2017–19 drought in subtropical eastern Australia with multiple flash droughts identified between June and December 2019. These occurrences were explained by a positive Indian Ocean dipole (IOD), a central Pacific El Niño Modoki, and a negative Southern Annular Mode. With type-3 flash droughts, there is debate as to whether they relate to fluctuations in north–south movement of the intertropical convergence zone [ITCZ; see Magaña et al. (1999), and Ramírez (1983), for different opinions], although it is widely held that they are prolonged by El Niño–Southern Oscillation (ENSO; Anderson et al. 2019; Casanova 1992). Therefore, for the United States, China, Australia and Central America, multiweek to seasonal prediction systems offer a certain degree of predictability since large-scale climate is more predictable than its cascading impacts over land. Type-2, type-4, and type-5 flash droughts seem more difficult to forecast and further research is needed. Traditionally, drought forecasting has focused on predicting climate variables such as temperature and precipitation, but our study shows that there is a need to improve forecasting of other variables such as soil moisture, wind speed, humidity, and cloud cover for accurate flash drought forecasting.

f. Opportunities

There are large regions of the world specified as flash drought hotspots on the maps in Fig. 1 for which we do not present examples, such as Southeast Asia, northern South America, and western Europe. This omission is due to the locations of survey responses; the social media promotion of the survey and targeted email campaign did not manage to incorporate all “corners” of the world. However, we found that flash drought type events seem to be occurring essentially ubiquitously. We therefore suspect that local nomenclature, characteristics, and impacts could be found almost anywhere. That is in addition to variations in local nomenclature, characteristics, and impacts probably occurring within the regions we presented given the spatial variability in locally important factors of susceptibility to flash drought. Relevant research outside of the United States and China is lacking, and improved understanding of region-specific flash droughts could contribute toward improved drought management. Further research could reveal additional locally important climatic features and nonclimatic factors that heighten susceptibility to flash drought, especially anthropogenic factors that can be most easily acted upon. Regionally, thorough diagnoses are required because different regions experience different flash drought types and have differing vulnerabilities, requiring contextualized indices, monitoring, adaptation and mitigation strategies (Walker et al. 2022). Reporting of flash drought impacts rarely extends beyond agricultural impacts. Such focus would be expected given the rapidly intensifying soil moisture drought; however, there is uncertainty over what other impacts are occurring (Otkin et al. 2022). Drought-impacts monitoring programs, citizen science or otherwise, should be designed to expand the reporting of impacts beyond agriculture to other sectors and affected populations and ecosystems.

Opportunities related to the monitoring of impacts are applicable to all drought-affected regions, not only those vulnerable to flash drought. Crowdsourcing programs, like the U.S. Condition Monitoring Observer Reports (CMOR; https://droughtimpacts.unl.edu/Tools/ConditionMonitoringObservations.aspx) could be expanded into other countries with similar drought monitors. Existing citizen science hydrometeorology programs could be expanded to also incorporate drought impacts, leveraging already motivated participants and existing software, a methodology applied in North America by the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS; https://www.cocorahs.org/Maps/conditionmonitoring/). Real-time monitoring of social media traffic with natural language processing (Zhang et al. 2021) may provide the high spatiotemporal resolution required to identify developing flash droughts.

Recent remote sensing applications provide a promising pathway forward to achieve the required high spatiotemporal resolution monitoring of soil moisture and large area coverage to identify developing flash droughts. Retrievals from NASA's ECOSTRESS enables surface temperature estimates at 70-m resolution, critical to capture crop heat stress (Fisher et al. 2020). For the western United States, crop water demand assessment at daily 30-m resolution were developed by the OpenET project (Melton et al. 2022) by using thermal and vegetative indices from satellite observations to estimate evapotranspiration using an ensemble modeling approach. Vergopolan et al. (2021b) combined SMAP hydrological modeling techniques to estimate soil moisture at 30-m resolution over the continental United States, demonstrating good spatial and temporal accuracy with ground observation. NASA's newly launched Surface Water and Ocean Topography (SWOT; https://swot.jpl.nasa.gov/) mission and upcoming NASA–Indian Space Research Organization (ISRO) synthetic aperture radar (SAR) (NISAR; https://nisar.jpl.nasa.gov/) mission aim to improve global freshwater monitoring by measuring river discharge and soil moisture, respectively. Direct measurements and approaches targeting integration of high-resolution soil, water, vegetation, and hydrometeorological conditions with impacts information, if implemented in near-real-time settings, could significantly contribute to improved spatial accuracy and reduce latency between drought occurrence and action. Given the rapid onset and local relevance, these advances are critical for flash drought mitigation and preparedness. A better understanding of what the existing flash drought indicators are telling us in different areas—as suggested by Osman et al. (2021) that different metrics may be capturing different stages or types of flash drought—could contribute toward development of early warning systems. Estimating lag time between climatic anomalies and experienced impacts is vital for the development of early warning systems (Lam et al. 2023). Similarly, comparing the intensity of climatic anomalies with experienced impacts can lead to development of impact-based forecasts to reveal what the weather will do, rather than what it will be (Trnka et al. 2020). The interrelated dynamics of natural and human influences that lead to "anthropogenic drought" are receiving more research attention (e.g., AghaKouchak et al. 2021; Savelli et al. 2022). However, as shown here, such research attention could be extended to human-induced flash drought.

5. Conclusions

Most flash drought definitions and indices are derived from the United States and China (Lisonbee et al. 2021), limiting their applicability to other regions. Global assessments based on these definitions (e.g., Christian et al. 2021; Limones 2021; Mukherjee and Mishra 2022; Qing et al. 2022) lack ground truthing to confirm the occurrence of impactful flash droughts in indicated hotspot locations. Our global survey and review of local literature and media revealed the occurrence of impactful flash drought events worldwide, often with region-specific characteristics. These events often hold cultural significance, evidenced by their local nomenclature. Examples from Latin America, Africa, Asia, and Europe showcased variations in duration, intensity, frequency, drivers, predictability, and impacts. We classified flash droughts into five types, unified by the rapid intensification of soil moisture or hydrological drought:

1) Type 1: Flash droughts that intensify over weeks, often evolving into prolonged drought.
2) Type 2: Short-duration flash droughts lasting from days to weeks occurring in the wet season.
3) Type 3: Mid-wet-season flash droughts related to a bimodal rainfall distribution.
4) Type 4: Short-duration flash droughts lasting from days to weeks driven by dry winds.
5) Type 5: Human-induced flash drought.

The existing flash drought indices may fail to detect these events due to their diverse characteristics, necessitating contextualized indices for effective drought adaptation and management measures. Factors such as timing, crop/vegetation type, soil type, agriculture practices, and socioeconomic vulnerability control the severity of impacts. To improve flash drought understanding, localized impact monitoring at high spatiotemporal resolution is essential for developing relevant indices and enhancing early warning systems. In addition, research on socioeconomic flash drought impacts should be expanded, addressing the areas identified in this study and beyond. Projected climate change amplifies the frequency, intensity, and extent of flash droughts (Rauscher et al. 2008; Yuan et al. 2019; Osman et al. 2021; Shah et al. 2022; Qing et al. 2022; Yuan et al. 2023; Walker and Van Loon 2023; Christian et al. 2023), underscoring the need for comprehensive inclusion of all drought types in drought research and management strategies (Walker and Van Loon 2023). Collaboration with affected communities to better understand different drought types is an effective initial step (Walker et al. 2022).

Acknowledgments. We thank all of those who completed the questionnaire prompting this review. First author Walker was supported by the project: "3DDD: Diagnosing drought for dealing with drought in 3D," funded by the Dutch Research Council (NWO) and the Interdisciplinary Research and Education Fund (INREF) of Wageningen University, the Netherlands (Grant W07.30318.016).

Data availability statement. This paper utilizes existing published material and does not analyze any new data.

APPENDIX

Questionnaire

The questionnaire, prepared with Typeform, was available online and is given here in its exact wording:

What are other terms for flash droughts around the world?

Hello everyone,

A group of researchers from the Panta Rhei Drought in the Anthropocene working group is in the early stage of researching flash droughts. It is from their knowledge that Brazil has a specific local term for flash droughts: *veranico*. Are there other terms used for flash droughts, or dry spells, in other parts of the globe? Can you help with this?

Answering the form will take 2 minutes of your time. If you do not know all the details but are only aware of the term used for flash drought locally in any particular region (questions 1 and 2), that information will already help us a lot.

Below each of the six questions is the example response (in italics) considering Northeast Brazil.

1) Where is the region (country, region, state, municipality, etc.)?
   e.g., Northeast Brazil
2) Local term for flash drought?
   Brazil example: Veranico
3) What are the defining characteristics (e.g., length, heat, etc.)?
   Brazil example: Approximately 5–15 day period of almost no rain during the growing season; not heat-related.
4) What are the main impacts (e.g., crop losses, human-health effects, loss of biodiversity, etc.)?
   Brazil example: Decreased crop yield
5) What are the causes and aggravating factors (e.g., crop choices, heat waves, soils, water availability, etc.)?
   Brazil example: Shallow poor soils mean soil moisture quickly depletes; timing is important (greater impact during crop flowering stage); few groundwater resources to buffer lack of rain
6) Is there any other relevant information you can provide?
   Brazil example: Most papers analyzing veranicos are in agronomy journals and mostly in Portuguese. Veranicos in the south of Brazil are considered a blessing as they are a break from the rains.
7) If you want to have further information about the research, please, write your name and e-mail. Thanks a lot for your time!

REFERENCES

Ademe, F., K. Kibret, S. Beyene, M. Getinet, and G. Mitike, 2020: Rainfall analysis for rain-fed farming in the Great Rift Valley basins of Ethiopia. *J. Water Climate Change*, **11**, 812–828, https://doi.org/10.2166/wcc.2019.242.

Adhikari, S., 2018: Drought impact and adaptation strategies in the mid-hill farming system of western Nepal. *Environments*, **5**, 101, https://doi.org/10.3390/environments5090101.

AghaKouchak, A., and Coauthors, 2021: Anthropogenic drought: Definition, challenges, and opportunities. *Rev. Geophys.*, **59**, e2019RG000683, https://doi.org/10.1029/2019RG000683.

Ajak, B. J., 2018: Livelihood resilience and adaptation to climate variability in post-conflict South Sudan—A review. *Agric. Rev.*, **39**, 193–201, https://doi.org/10.18805/ag.R-1788.

Alfaro, E. J., 2014: Characterization of the mid-summer drought in two Pacific slope river basins of Costa Rica, Central America (in Spanish). *Rev. Biol. Trop.*, **62** (4), 1–15, https://doi.org/10.15517/rbt.v62i4.20010.

Allen, T., P. Heinrigs, and I. Heo, 2018: Agriculture, food and jobs in West Africa. West African Papers 14, 33 pp., https://www.oecd-ilibrary.org/docserver/dc152bc0-en.pdf.

Amar Ujala Bureau, 2017: The winds were withered crops (in Hindi). Amar Ujala Bureau, accessed 3 December 2022, https://www.amarujala.com/uttar-pradesh/farrukhabad/the-winds-were-withered-crops.

Anderson, M. C., and Coauthors, 2016: The evaporative stress index as an indicator of agricultural drought in Brazil: An assessment based on crop yield impacts. *Remote Sens. Environ.*, **174**, 82–99, https://doi.org/10.1016/j.rse.2015.11.034.

Anderson, T. G., K. J. Anchukaitis, D. Pons, and M. Taylor, 2019: Multiscale trends and precipitation extremes in the Central American midsummer drought. *Environ. Res. Lett.*, **14**, 124016, https://doi.org/10.1088/1748-9326/ab5023.

Araya, A., and L. Stroosnijder, 2011: Assessing drought risk and irrigation need in northern Ethiopia. *Agric. For. Meteor.*, **151**, 425–436, https://doi.org/10.1016/j.agrformet.2010.11.014.

Aryal, M., A. Giri, D. B. Basnet, and M. Kandel, 2018: Policy framework for climate-induced disaster risk management in agriculture sector of Nepal. *J. Agric. Environ.*, **19**, 59–70.

Associated Press, 2022: East and Horn of Africa prep for worst drought in decades. NBC News, accessed 10 July 2022, https://www.nbcnews.com/science/science-news/east-horn-africa-prep-worst-drought-decades-rcna24348.

Ati, O. F., C. J. Stigter, and E. O. Oladipo, 2002: A comparison of methods to determine the onset of the growing season in northern Nigeria. *Int. J. Climatol.*, **22**, 731–742, https://doi.org/10.1002/joc.712.

Bachmair, S., and Coauthors, 2016: Drought indicators revisited: The need for a wider consideration of environment and society. *Wiley Interdiscip. Rev.: Water*, **3**, 516–536, https://doi.org/10.1002/wat2.1154.

Barron, J., J. Rockström, F. Gichuki, and N. Hatibu, 2003: Dry spell analysis and maize yields for two semi-arid locations in East Africa. *Agric. For. Meteor.*, **117**, 23–37, https://doi.org/10.1016/S0168-1923(03)00037-6.

Bekele, D., T. Alamirew, A. Kebede, G. Zeleke, and A. M. Melesse, 2017: Analysis of rainfall trend and variability for agricultural water management in Awash River Basin, Ethiopia. *J. Water Climate Change*, **8**, 127–141, https://doi.org/10.2166/wcc.2016.044.

Bendixen, M., L. L. Iversen, J. Best, D. M. Franks, C. R. Hackney, E. M. Latrubesse, and L. S. Tusting, 2021: Sand, gravel, and UN sustainable development goals: Conflicts, synergies, and pathways forward. *One Earth*, **4**, 1095–1111, https://doi.org/10.1016/j.oneear.2021.07.008.

Bergamaschi, H., and Coauthors, 2006: Water deficit and yield in maize crop (in Portuguese). *Pesqui. Agropecu. Bras.*, **41**, 243–249, https://doi.org/10.1590/S0100-204X2006000200008.

Bewket, W., and D. Conway, 2007: A note on the temporal and spatial variability of rainfall in the drought-prone Amhara region of Ethiopia. *Int. J. Climatol.*, **27**, 1467–1477, https://doi.org/10.1002/joc.1481.

Biasutti, M., 2019: Rainfall trends in the African Sahel: Characteristics, processes, and causes. *Wiley Interdiscip. Rev.: Climate Change*, **10**, e591, https://doi.org/10.1002/wcc.591.

Bisht, G., 2022: Dry spell worries apple growers in Himachal. *Hindustan Times*, 29 March, https://www.hindustantimes.com/cities/chandigarh-news/dry-spell-worries-apple-growers-in-himachal-101648554215250.html.

Bouwer, L. M., 2011: Have disaster losses increased due to anthropogenic climate change? *Bull. Amer. Meteor. Soc.*, **92**, 39–46, https://doi.org/10.1175/2010BAMS3092.1.

Buchinskij, I. E., 1970: *Droughts, Dry Winds and Dust Storms in Ukraine and the Fight Against Them (in Russian)*. Urozhaj, 236 pp.

Cai, W., P. Sun, C. Xia, H. Li, Q. Zhang, and H. Li, 2021: Spatio-temporal evolution of flash droughts in eastern monsoon region according to different soil types. *J. Beijing Norm. Univ.*, **57**, 834–844, https://doi.org/10.12202/j.0476-0301.2020335.

Carvajal Montoya, J. E., 2014: Implementación de una metodología participativa de estrategias de adaptación al cambio climático en recursos hídricos en la parte alta de la cuenca del Río Reventado, Cartago, Costa Rica. M.S. thesis, Centro Agronómico Tropical de Investigación y Enseñanza, 105 pp., https://repositorio.catie.ac.cr/bitstream/handle/11554/7081/Implementacion_de_una_metodologia_participativa.pdf.

Casanova, O. P., 1992: Riesgo por sequías en Costa Rica. *Rev. Geogr. Amer. Cent.*, **1**, 385–411.

Chen, L. G., J. Gottschalck, A. Hartman, D. Miskus, R. Tinker, and A. Artusa, 2019: Flash drought characteristics based on U.S. Drought Monitor. *Atmosphere*, **10**, 498, https://doi.org/10.3390/atmos10090498.

Chen, S., 2005: *Severe Drought with High Temperature in 2003 over the Jiangxi Province, China (in Chinese)*. China Meteorological Press, 298 pp.

Christian, J. I., J. B. Basara, J. A. Otkin, and E. D. Hunt, 2019: Regional characteristics of flash droughts across the United States. *Environ. Res. Commun.*, **1**, 125004, https://doi.org/10.1088/2515-7620/ab50ca.

——, ——, E. D. Hunt, J. A. Otkin, J. C. Furtado, V. Mishra, X. Xiao, and R. M. Randall, 2021: Global distribution, trends, and drivers of flash drought occurrence. *Nat. Commun.*, **12**, 6330, https://doi.org/10.1038/s41467-021-26692-z.

——, and Coauthors, 2023: Global projections of flash drought show increased risk in a warming climate. *Commun. Earth Environ.*, **4**, 165, https://doi.org/10.1038/s43247-023-00826-1.

Comisión Económica para América Latina y El Caribe, 2002: El Impacto Socioeconómico y Ambiental de la Sequía de 2001 en Centroamérica. United Nations, 68 pp., https://www.gfdrr.org/sites/default/files/publication/pda-2001-centralamerica.pdf.

Dangar, S., and V. Mishra, 2021: Natural and anthropogenic drivers of the lost groundwater from the Ganga River basin. *Environ. Res. Lett.*, **16**, 114009, https://doi.org/10.1088/1748-9326/ac2ceb.

de Andrade, E. M., M. G. T. Sena, A. G. R. da Silva, F. J. S. Pereira, and F. B. Lopes, 2016: Uncertainties of the rainfall regime in a tropical semi-arid region: The case of the state of Ceará. *Braz. J. Agrar. Environ. Sci.*, **10**, 88–95, https://doi.org/10.18227/1982-8470ragro.v10i2.3500.

de Carvalho, D. F., R. A. de Faria, S. A. V. de Sousa, and H. Q. Borges, 2000: Espacialização do período de veranico para diferentes níveis de perda de produção na cultura do milho, na bacia do Rio Verde Grande, MG. *Rev. Bras. Eng. Agric. Ambiental*, **4**, 172–176.

Deshpande, S., 2019: Dry spell leaves Beed farmers in a lurch. *Hindustan Times*, 28 July, https://www.hindustantimes.com/india-news/dry-spell-leaves-beed-farmers-in-a-lurch/story-k6xS7yc7FmQ6wh5Btny3jO.html.

Doyle, K., 2019: "Flash droughts" strike fast and hard, and researchers are still racing to identify them before they happen. ABC News, accessed 19 September 2022, https://www.abc.net.au/news/2019-07-20/how-flash-droughts-strike-fast-and-hard/11320654.

Duginski, P., 2022: Why it's been so warm and windy in Southern California this winter. *LA Times*, 12 March, https://www.latimes.com/california/story/2022-03-12/why-its-been-so-warm-and-windy-in-southern-california-this-winter.

Echeverría, J., 2016: Socio-economic analysis of the sectoral impacts of the 2014 drought in Central America. Global Water Partnership, 56 pp., https://www.droughtmanagement.info/literature/GWP_CAM_Drought-2014-Impact_eng.pdf.

Edris, S. G., J. B. Basara, J. I. Christian, E. D. Hunt, J. A. Otkin, S. T. Salesky, and B. G. Illston, 2023: Analysis of the critical components of flash drought using the standardized evaporative stress ratio. *Agric. For. Meteor.*, **330**, 109288, https://doi.org/10.1016/j.agrformet.2022.109288.

Entremundos, 2017: Hunger caused by climate change is driving migration to the US. Entremundos, accessed 14 February 2022, https://www.entremundos.org/revista/uncategorized/climate-change-induced-hunger-is-pushing-migration-to-the-us/?lang=en.

Fahad, S., and Coauthors, 2017: Crop production under drought and heat stress: Plant responses and management options. *Front. Plant Sci.*, **8**, 1147, https://doi.org/10.3389/fpls.2017.01147.

Famine Early Warning Systems Network, 2022: Food security outlook: Uganda. Accessed 21 July 2022, https://fews.net/east-africa/uganda/food-security-outlook/june-2022.

FAO, 2019: Erratic weather patterns in the Central American Dry Corridor leave 1.4 million people in urgent need of food assistance. United Nations, accessed 9 April 2022, https://www.fao.org/news/story/en/item/1191887/icode/.

Fisher, J. B., and Coauthors, 2020: ECOSTRESS: NASA's next generation mission to measure evapotranspiration from the international space station. *Water Resour. Res.*, **56**, e2019WR026058, https://doi.org/10.1029/2019WR026058.

Flores Mora, C., 2014: Record drought in Central America: Four countries, 40 days without rain, two million facing hunger. The World Bank, accessed 1 June 2022, https://www.worldbank.org/en/news/feature/2014/09/10/sequias-centroamerica.

Ford, T. W., D. B. McRoberts, S. M. Quiring, and R. E. Hall, 2015: On the utility of in situ soil moisture observations for flash drought early warning in Oklahoma, USA. *Geophys. Res. Lett.*, **42**, 9790–9798, https://doi.org/10.1002/2015GL066600.

Froidurot, S., and A. Diedhiou, 2017: Characteristics of wet and dry spells in the West African monsoon system. *Atmos. Sci. Lett.*, **18**, 125–131, https://doi.org/10.1002/asl.734.

Grindlay, D., 2015: Surveying the damage of an October summer on Wimmera grain belt: Poor, poorer and plain horrific. ABC News Rural, accessed 19 September 2022, http://www.abc.net.au/news/rural/2015-10-16/drought-wimmera-rain-grain-debt-heatwave-crops/6861680.

Guerreiro, M. J. S., E. M. de Andrade, I. Abreu, and T. Lajinha, 2013: Long-term variation of precipitation indices in Ceará state, Northeast Brazil. *Int. J. Climatol.*, **33**, 2929–2939, https://doi.org/10.1002/joc.3645.

Hadebe, S. T., A. T. Modi, and T. Mabhaudhi, 2017: Drought tolerance and water use of cereal crops: A focus on sorghum as a food security crop in sub-Saharan Africa. *J. Agron. Crop Sci.*, **203**, 177–191, https://doi.org/10.1111/jac.12191.

Hassan, R., 2021: Kashmir's apples scorched by the sun, need help from the heavens. *Kashmir Reader*, 1 October, https://kashmirreader.com/2021/10/01/kashmirs-apples-scorched-by-the-sun-need-help-from-the-heavens/.

Heim, R. R., Jr., C. Guard, M. A. Lander, and B. Bukunt, 2020: USAPI USDM: Operational drought monitoring in the U.S.-affiliated Pacific Islands. *Atmosphere*, **11**, 495, https://doi.org/10.3390/atmos11050495.

Hoell, A., and Coauthors, 2020: Lessons learned from the 2017 flash drought across the U.S. northern Great Plains and Canadian Prairies. *Bull. Amer. Meteor. Soc.*, **101**, E2171–E2185, https://doi.org/10.1175/BAMS-D-19-0272.1.

Hoerling, M., J. Eischeid, A. Kumar, R. Leung, A. Mariotti, K. Mo, S. Schubert, and R. Seager, 2014: Causes and predictability of the 2012 Great Plains drought. *Bull. Amer. Meteor. Soc.*, **95**, 269–282, https://doi.org/10.1175/BAMS-D-13-00055.1.

Hulme, M., 2001: Climatic perspectives on Sahelian desiccation: 1973–1998. *Global Environ. Change*, **11**, 19–29, https://doi.org/10.1016/S0959-3780(00)00042-X.

Hunt, E. D., and Coauthors, 2020: The flash drought of 1936. *J. Appl. Serv. Climatol.*, 2020 (4), https://doi.org/10.46275/JOASC.2020.11.001.

Jagran, 2022: Climate change affects Rabi crops, farmers worried (in Hindi). *Jagran*, 20 February, https://www.jagran.com/uttar-pradesh/chandauli-weather-change-affects-rabi-crops-annadata-worried-22482861.html.

Jamir, M., 2021: 'Drought-like' Nagaland stares at water scarcity, low harvest. Down to Earth, accessed 22 June 2022, https://www.downtoearth.org.in/news/water/-drought-like-nagaland-stares-at-water-scarcity-low-harvest-78594.

Jardim, C. H., 2012: "Médias" e "desvios" na análise geográfico-climatológica: O episódio de chuva concentrada do dia 23 de novembro de 2010 e o veranico de janeiro/fevereiro de 2011 em Belo Horizonte-MG. *Rev. Geogr.*, **8**, 35–49, https://doi.org/10.35699/2237-549X..13328.

Jha, R., A. Mondal, A. Devanand, M. K. Roxy, and S. Ghosh, 2022: Limited influence of irrigation on pre-monsoon heat stress in the Indo-Gangetic Plain. *Nat. Commun.*, **13**, 4275, https://doi.org/10.1038/s41467-022-31962-5.

Jin, Y., J. T. Randerson, N. Faivre, S. Capps, A. Hall, and M. L. Goulden, 2014: Contrasting controls on wildland fires in Southern California during periods with and without Santa Ana winds. *J. Geophys. Res. Biogeosci.*, **119**, 432–450, https://doi.org/10.1002/2013JG002541.

Jiri, O., P. Mafongoya, C. Mubaya, and O. Mafongoya, 2016: Seasonal climate prediction and adaptation using indigenous knowledge systems in agriculture systems in southern Africa: A review. *J. Agric. Sci.*, **8**, 156–172, https://doi.org/10.5539/jas.v8n5p156.

Kang, X., Z. Le, C. Li, L. Dai, C. Quan, M. Shi, and R. Liao, 2022: Study on the different responses of different winter wheat cultivars to dry hot wind. *PLOS ONE*, **17**, e0274118, https://doi.org/10.1371/journal.pone.0274118.

Kebede, A., B. Diekkrüger, and D. C. Edossa, 2017: Dry spell, onset and cessation of the wet season rainfall in the upper Baro-Akobo Basin, Ethiopia. *Theor. Appl. Climatol.*, **129**, 849–858, https://doi.org/10.1007/s00704-016-1813-y.

Keener, V. W., S. K. Izuka, and S. Anthony, 2012: Freshwater and drought on Pacific Islands. *Climate Change and Pacific Islands: Indicators and Impacts*, J. J. Marra et al., Eds., Island Press, 35–64.

Konrad, C. E., II, and P. Knox, 2017: The southeastern drought and wildfires of 2016. Tech. Rep. The Southeast Regional Climate Center, 85 pp., https://drought.unl.edu/archive/assessments/Southeast_wildfire_2016_Konrad_Knox.pdf.

Kumar, R. K., 2021: Alarm bells over shifting rainfall pattern. *The Hindu*, 26 December, https://www.thehindu.com/news/national/karnataka/alarm-bells-over-shifting-rainfall-pattern/article38042818.ece.

Lam, M. R., and Coauthors, 2023: Linking reported drought impacts with drought indices, water scarcity, and aridity: The case of Kenya. *Nat. Hazards Earth Syst. Sci.*, **23**, 2915–2936, https://doi.org/10.5194/nhess-23-2915-2023.

Lasania, Y. Y., 2018: Dry spells leave Telangana farmers worried. *Mint*, 21 June, https://www.livemint.com/Politics/ALMWZaUwHsu6v31k6sKaHM/Dry-spell-leaves-Telangana-farmers-worried.html.

Lawal, P. O., 2011: Effects of sand/gravel mining in Minna Emirate area of Nigeria on stakeholders. *J. Sustainable Dev.*, **4**, 193–199, https://doi.org/10.5539/jsd.v4n1p193.

Lebel, T., and A. Ali, 2009: Recent trends in the central and western Sahel rainfall regime (1990–2007). *J. Hydrol.*, **375**, 52–64, https://doi.org/10.1016/j.jhydrol.2008.11.030.

Leeper, R. D., and Coauthors, 2022: Characterizing U.S. drought over the past 20 years using the U.S. Drought Monitor. *Int. J. Climatol.*, **42**, 6616–6630, https://doi.org/10.1002/joc.7653.

Lemma, M. U., A. Alemie, S. Habtu, and C. Lemma, 2016: Analyzing the impacts of on onset, length of growing period and dry spell length on chickpea production in Adaa District (East Showa Zone) of Ethiopia. *J. Earth Sci. Climate Change*, **7**, 349, https://doi.org/10.4172/2157-7617.1000349.

Leonard, D., 2022: Southwest drought is the most extreme in 1,200 years, study finds. *The Washington Post*, 14 February, https://www.washingtonpost.com/weather/2022/02/14/southwest-megadrought-worst-1200-years/.

Li, J., Z. Wang, X. Wu, J. Chen, S. Guo, and Z. Zhang, 2020: A new framework for tracking flash drought events in space and time. *CATENA*, **194**, 104763, https://doi.org/10.1016/j.catena.2020.104763.

Limones, N., 2021: A global-scale overview of precipitation-deficit flash droughts. *Terr. Atmos. Ocean. Sci.*, **32**, 597–611, https://doi.org/10.3319/TAO.2021.09.16.01.

Lisonbee, J., M. Woloszyn, and M. Skumanich, 2021: Making sense of flash drought: Definitions, indicators, and where we go from here. *J. Appl. Serv. Climatol.*, **2021**, https://doi.org/10.46275/JOASC.2021.02.001.

——, J. Ribbe, J. A. Otkin, and C. Pudmenzky, 2022: Wet season rainfall onset and flash drought: The case of the northern Australian wet season. *Int. J. Climatol.*, **42**, 6499–6514, https://doi.org/10.1002/joc.7609.

Liu, Y., Y. Zhu, L. Ren, J. Otkin, E. D. Hunt, X. Yang, F. Yuan, and S. Jian, 2020: Two different methods for flash drought identification: Comparison of their strengths and limitations. *J. Hydrometeor.*, **21**, 691–704, https://doi.org/10.1175/JHM-D-19-0088.1.

——, ——, L. Zhang, L. Zheng, L. Ren, and Y. Jia, 2021: Precedent meteorological driving forces of flash drought and their feasibility for flash drought simulation. *Adv. Water Sci.*, **32**, 497–507, https://doi.org/10.14042/j.cnki.32.1309.2021.04.002.

Lydolph, P. E., 1964: The Russian Sukhovey. *Ann. Assoc. Amer. Geogr.*, **54**, 291–309.

——, and T. B. Williams, 1982: The North American Sukhovey. *Ann. Assoc. Amer. Geogr.*, **72**, 224–236, https://doi.org/10.1111/j.1467-8306.1982.tb01821.x.

Madaan, N., 2017: Shower shortfall, heatwave to hit Nagpur oranges' production. *Times of India*, 13 August, https://timesofindia.indiatimes.com/city/pune/shower-shortfall-heatwave-to-hit-nagpur-oranges-production/articleshow/60039580.cms.

Magalhães, A. R., and M. H. Glantz, 1992: Socioeconomic impacts of climate variations and policy responses in Brazil. United Nations Environment Program (UNEP), Secretariat for Planning and Coordination State of Ceara (SEPLAN), Esquel Brasil Foundation, 156 pp., https://wedocs.unep.org/20.500.11822/30367.

Magaña, V., J. A. Amador, and S. Medina, 1999: The midsummer drought over Mexico and Central America. *J. Climate*, **12**, 1577–1588, https://doi.org/10.1175/1520-0442(1999)012<1577:TMDOMA>2.0.CO;2.

Mahdi, S. S., B. S. Dhekale, S. R. Choudhury, S. A. Bangroo, and S. K. Gupta, 2015: On the climate risks in crop production and management in India: A review. *Aust. J. Crop Sci.*, **9**, 585–595, https://search.informit.org/doi/10.3316/informit.35.

Mahto, S. S., and V. Mishra, 2020: Dominance of summer monsoon flash droughts in India. *Environ. Res. Lett.*, **15**, 104061, https://doi.org/10.1088/1748-9326/ABAF1D.

Mamo, G., M. Getnet, and G. Legesse, 2016: Managing dry spell risks to improve rainfed maize productivity in the semi-arid central rift valley of Ethiopia. *Ethiop. J. Agric. Sci.*, **26**, 99–109.

Marteau, R., B. Sultan, V. Moron, A. Alhassane, C. Baron, and S. B. Traore, 2011: The onset of the rainy season and farmers' sowing strategy for pearl millet cultivation in southwest Niger. *Agric. For. Meteor.*, **151**, 1356–1369, https://doi.org/10.1016/j.agrformet.2011.05.018.

McHugh, O. V., T. S. Steenhuis, A. Berihun, and E. C. M. Fernandes, 2007: Performance of in situ rainwater conservation tillage techniques on dry spell mitigation and erosion control in the drought-prone North Wello zone of the Ethiopian highlands. *Soil Tillage Res.*, **97**, 19–36, https://doi.org/10.1016/j.still.2007.08.002.

Melton, F. S., and Coauthors, 2022: OpenET: Filling a critical data gap in water management for the western United States. *J. Amer. Water Resour. Assoc.*, **58**, 971–994, https://doi.org/10.1111/1752-1688.12956.

Menezes, H. E. A., J. I. B. de Brito, and R. A. F. de A. Lima, 2010: Veranico e a produção agrícola no Estado da Paraíba, Brasil. *Rev. Bras. Eng. Agric. Ambiental*, **14**, 181–186, https://doi.org/10.1590/S1415-43662010000200009.

——, R. M. de Medeiros, J. L. G. Santos, T. S. Lima, and T. A. Pimenta, 2015: Influência de veranico na produção agrícola no município de Santa Filomena, Piauí, Brasil. *Rev. Verde Agroecol. Desenvolvimento Sustentável*, **10**, 21–25, https://doi.org/10.18378/rvads.v10i4.4608.

Mohanty, H., 2021: Deficient rainfall affects paddy, triggers drought fears in Odisha. Down to Earth, accessed 19 July 2022, https://www.downtoearth.org.in/news/agriculture/deficient-rainfall-affects-paddy-triggers-drought-fears-in-odisha-78468.

Motha, R. P., and T. R. Heddinghaus, 1986: The joint agricultural weather facility's operational assessment program. *Bull. Amer. Meteor. Soc.*, **67**, 1114–1122, https://doi.org/10.1175/1520-0477(1986)067<1114:TJAWFO>2.0.CO;2.

Mukherjee, S., and A. K. Mishra, 2022: A multivariate flash drought indicator for identifying global hotspots and associated climate controls. *Geophys. Res. Lett.*, **49**, e2021GL096804, https://doi.org/10.1029/2021GL096804.

——, A. Mishra, and K. E. Trenberth, 2018: Climate change and drought: A perspective on drought indices. *Curr. Climate Change Rep.*, **4**, 145–163, https://doi.org/10.1007/s40641-018-0098-x.

Mutasa, M., 2010: Zimbabwe's Drought Conundrum: Vulnerability and coping in Buhera and Chikomba districts. M.S. thesis, Dept. of International Environment and Development Studies, Norwegian University of Life Sciences, 178 pp.

Nepal Climate Vulnerability Study Team, 2009: Vulnerability through the eyes of the vulnerable: Climate change induced uncertainties and Nepal's development predicaments. Institute for Social and Environmental Transition, Nepal, Kathmandu and Institute for Social and Environmental Transition, 114 pp., https://www.preventionweb.net/files/12565_ClimatescenariosReport1.pdf.

Nguyen, H., M. C. Wheeler, J. A. Otkin, T. Cowan, A. Frost, and R. Stone, 2019: Using the evaporative stress index to monitor flash drought in Australia. *Environ. Res. Lett.*, **14**, 064016, https://doi.org/10.1088/1748-9326/ab2103.

——, ——, H. H. Hendon, E.-P. Lim, and J. A. Otkin, 2021: The 2019 flash droughts in subtropical eastern Australia and their association with large-scale climate drivers. *Wea. Climate Extremes*, **32**, 100321, https://doi.org/10.1016/j.wace.2021.100321.

Nielsen-Gammon, J. W., 2012: The 2011 Texas drought. *Tex. Water J.*, **3**, 59–95, https://doi.org/10.21423/twj.v3i1.6463.

Osman, M., B. F. Zaitchik, H. S. Badr, J. I. Christian, T. Tadesse, J. A. Otkin, and M. C. Anderson, 2021: Flash drought onset over the contiguous United States: Sensitivity of inventories and trends to quantitative definitions. *Hydrol. Earth Syst. Sci.*, **25**, 565–581, https://doi.org/10.5194/hess-25-565-2021.

Otkin, J. A., M. Svoboda, E. D. Hunt, T. W. Ford, M. C. Anderson, C. Hain, and J. B. Basara, 2018: Flash droughts: A review and assessment of the challenges imposed by rapid-onset droughts in the United States. *Bull. Amer. Meteor. Soc.*, **99**, 911–919, https://doi.org/10.1175/BAMS-D-17-0149.1.

——, and Coauthors, 2022: Getting ahead of flash drought: From early warning to early action. *Bull. Amer. Meteor. Soc.*, **103**, E2188–E2202, https://doi.org/10.1175/BAMS-D-21-0288.1.

Padmalal, D., and K. Maya, 2014: Impacts of river sand mining. *Sand Mining: Environmental Impacts and Selected Case Studies*, D. Padmalal and K. Maya, Eds., Environmental Science and Engineering, Springer, 31–56.

Parker, T., A. Gallant, M. Hobbins, and D. Hoffmann, 2021: Flash drought in Australia and its relationship to evaporative demand. *Environ. Res. Lett.*, **16**, 064033, https://doi.org/10.1088/1748-9326/abfe2c.

Pendergrass, A. G., and Coauthors, 2020: Flash droughts present a new challenge for subseasonal-to-seasonal prediction. *Nat. Climate Change*, **10**, 191–199, https://doi.org/10.1038/s41558-020-0709-0.

Poonia, V., M. K. Goyal, S. Jha, and S. Dubey, 2022: Terrestrial ecosystem response to flash droughts over India. *J. Hydrol.*, **605**, 127402, https://doi.org/10.1016/j.jhydrol.2021.127402.

Prajapati, R., R. Talchabhadel, P. Silwal, S. Upadhyay, B. Ertis, B. R. Thapa, and J. C. Davids, 2021: Less rain and rainy days—Lessons from 45 years of rainfall data (1971–2015) in the Kathmandu Valley, Nepal. *Theor. Appl. Climatol.*, **145**, 1369–1383, https://doi.org/10.1007/s00704-021-03706-w.

Pulwarty, R. S., and M. V. K. Sivakumar, 2014: Information systems in a changing climate: Early warnings and drought risk management. *Wea. Climate Extremes*, **3**, 14–21, https://doi.org/10.1016/j.wace.2014.03.005.

Qing, Y., S. Wang, B. C. Ancell, and Z.-L. Yang, 2022: Accelerating flash droughts induced by the joint influence of soil moisture depletion and atmospheric aridity. *Nat. Commun.*, **13**, 1139, https://doi.org/10.1038/s41467-022-28752-4.

Rajeevan, M., S. Gadgil, and J. Bhate, 2010: Active and break spells of the Indian summer monsoon. *J. Earth Syst. Sci.*, **119**, 229–247, https://doi.org/10.1007/s12040-010-0019-4.

Ramírez, P., 1983: Estudio Meteorologico de Los Veranillos en Costa Rica. Nota de Investigacion 5, 50 pp., https://www.imn.ac.cr/documents/10179/20909/Estudio+sobre+veranillos+en+Costa+Rica.

Rana, S. V. S., 2007: *Essentials of Ecology and Environmental Science*. Prentice-Hall of India Pvt. Ltd., 608 pp.

Rauscher, S. A., F. Giorgi, N. S. Diffenbaugh, and A. Seth, 2008: Extension and intensification of the Meso-American midsummer drought in the twenty-first century. *Climate Dyn.*, **31**, 551–571, https://doi.org/10.1007/s00382-007-0359-1.

Redmond, K. T., 2002: The depiction of drought: A commentary. *Bull. Amer. Meteor. Soc.*, **83**, 1143–1148, https://doi.org/10.1175/1520-0477-83.8.1143.

Regmi, H. R., 2007: Effect of unusual weather on cereal crop production and household food security. *J. Agric. Environ.*, **8**, 20–29, https://doi.org/10.3126/aej.v8i0.723.

Reis, G. P., D. da Silva Brito, F. M. de Alencar Silva, S. G. de Oliveira, and S. C. Ribeiro, 2011: Propensões dos veranicos no núcleo de desertificação dos inhamuns no ceará (1979–2011). *III Simpósio de Mudanças Climáticas e Desertificação no Semiárido Brasileiro*, Juazeiro, Brazil, Embrapa, http://www.cpatsa.embrapa.br/smud/trabalhos/62_1_inscrito_2.doc.

Rocha, T. B. C., F. C. Vasconcelos Jr., C. S. Silveira, E. S. P. R. Martins, and R. F. V. Silva, 2020: Veranicos no ceará e aplicações para agricultura de sequeiro. *Rev. Bras. Meteor.*, **35**, 435–447, https://doi.org/10.1590/0102-7786353005.

Rockström, J., 2003: Resilience building and water demand management for drought mitigation. *Phys. Chem. Earth*, **28**, 869–877, https://doi.org/10.1016/j.pce.2003.08.009.

Rosa, L., 2022: Adapting agriculture to climate change via sustainable irrigation: Biophysical potentials and feedbacks. *Environ. Res. Lett.*, **17**, 063008, https://doi.org/10.1088/1748-9326/ac7408.

Saini, S., and S. Das, 2021: 2021 monsoon shows impact of climate change. Here's what it's doing to kharif crops. *ThePrint*, 17 November, https://theprint.in/opinion/2021-monsoon-shows-impact-of-climate-change-heres-what-its-doing-to-kharif-crops/767231/.

Salack, S., K. Hien, N. Z. Lawson, I. A. Saley, J.-E. Paturel, and M. Waongo, 2020: Prévisibilité des faux-départs de saison agricole au Sahel. *Risques Climatiques et Agriculture en Afrique de l'Ouest*, B. Sultan et al., Eds., IRD, 31–43.

Samachar Nama, 2021: Ganganagar westerly winds lasted more than two months and Toute spoiled the system, rainfall reduced by 43.53 percent in monsoon (in Hindi). Samachar Nama, accessed 11 May 2022, https://samacharnama.com/states/ganganagar-westerly-winds-lasted-more-than-two-months-and/cid5068964.htm.

Sambo, B. E., 2014: Endangered, neglected, indigenous resilient crops: A potential against climate change impact for sustainable crop productivity and food security. *IOSR J. Agric. Vet. Sci.*, **7**, 34–41, https://doi.org/10.9790/2380-07223441.

Samra, J. S., G. Singh, and Y. Ramakrishna, 2003: *Cold Wave of 2002-03—Impact on Agriculture*. Indian Council of Agricultural Research, 62 pp., https://un-spider.org/sites/default/files/6-Cold%20Wave_Impacts_India_Indian%20Council%20of%20Agricultural%20Research.pdf.

Saporoschenko, A., 2011: The effect of Santa Ana wind conditions and cloudiness on Southern California stock returns. *Appl. Financ. Econ.*, **21**, 683–694, https://doi.org/10.1080/09603107.2010.535785.

Satyamurty, P., and C. K. Padilha, 2006: Warm and dry spells (WDS) in austral winter in tropical and subtropical South America. *Proc. Eighth ICSHMO*, Foz do Iguaçu, Brazil, INPE, 1985–1995, http://mtc-m16b.sid.inpe.br/col/cptec.inpe.br/adm_conf/2005/11.01.13.03/doc/1985-1996.pdf.

Savelli, E., M. Rusca, H. Cloke, and G. Di Baldassarre, 2022: Drought and society: Scientific progress, blind spots, and future prospects. *Wiley Interdiscip. Rev.: Climate Change*, **13**, e761, https://doi.org/10.1002/wcc.761.

Segele, Z., and P. Lamb, 2005: Characterization and variability of Kiremt rainy season over Ethiopia. *Meteor. Atmos. Phys.*, **89**, 153–180, https://doi.org/10.1007/s00703-005-0127-x.

Seleshi, Y., and P. Camberlin, 2006: Recent changes in dry spell and extreme rainfall events in Ethiopia. *Theor. Appl. Climatol.*, **83**, 181–191, https://doi.org/10.1007/s00704-005-0134-3.

Semenova, I., and M. Slizhe, 2020: Synoptic conditions of droughts and dry winds in the Black Sea Steppe Province under recent decades. *Front. Earth Sci.*, **8**, 69, https://doi.org/10.3389/feart.2020.00069.

Sengupta, R., V. Kumar, N. Jamwal, A. Panda, Jitendra, and S. Venkatesh, 2017: Unpredictable weather, unreliable insurance, unbelievable profit to companies. Down to Earth, accessed 11 July 2022, https://www.downtoearth.org.in/coverage/agriculture/unpredictable-weather-unreliable-insurance-unbelievable-profit-to-companies-58431.

Shah, J., and Coauthors, 2022: Increasing footprint of climate warming on flash droughts occurrence in Europe. *Environ. Res. Lett.*, **17**, 064017, https://doi.org/10.1088/1748-9326/ac6888.

Shaktilochan, T., 2021: Weather alert: Direction of westerly wind became uncontrolled in this district of Bihar, fear of fire increased, know special advice . . . (in Hindi). *Prabhat Khabar*, 17 April, https://www.prabhatkhabar.com/state/bihar/patna/bihar-weather-report-as-pachua-hawa-in-bihar-mausam-vibhag-alert-for-fire-precautions-at-home-news-skt.

Singh, G., 2010: *A Geography of India*. 9th ed. Atma Ram and Sons, 560 pp.

Smith, K. H., and Coauthors, 2023: Baseline assessment of drought impact collection/monitoring efforts 2022. U.S. National Drought Mitigation Center for the Integrated Drought Management Programme, in press.

Sultan, B., C. Baron, M. Dingkuhn, B. Sarr, and S. Janicot, 2005: Agricultural impacts of large-scale variability of the West African monsoon. *Agric. For. Meteor.*, **128**, 93–110, https://doi.org/10.1016/j.agrformet.2004.08.005.

Sun, L., H. Li, M. N. Ward, and D. F. Moncunill, 2007: Climate variability and corn yields in semiarid Ceará, Brazil. *J. Appl. Meteor. Climatol.*, **46**, 226–240, https://doi.org/10.1175/JAM2458.1.

Svoboda, M., and Coauthors, 2002: The Drought Monitor. *Bull. Amer. Meteor. Soc.*, **83**, 1181–1190, https://doi.org/10.1175/1520-0477-83.8.1181.

Tamiru, S., K. Tesfaye, and G. Mamo, 2015: Analysis of rainfall and temperature variability to guide sorghum (sorghum bicolar) production in miesso areas, eastern Ethiopia. *Int. J. Sustainable Agric. Res.*, **2** (1), 1–11, https://doi.org/10.18488/journal.70/2015.2.1/70.1.1.11.

Tavakol, A., V. Rahmani, and J. Harrington Jr., 2020: Temporal and spatial variations in the frequency of compound hot, dry, and windy events in the central United States. *Sci. Rep.*, **10**, 15691, https://doi.org/10.1038/s41598-020-72624-0.

Taylor, M., 2019: Once gushing with water, Nepal's springs are rapidly drying up. *The Kathmandu Post*, 29 November, https://kathmandupost.com/climate-environment/2019/11/29/once-gushing-with-water-nepal-s-springs-are-rapidly-drying-up.

Trenberth, K. E., and C. J. Guillemot, 1996: Physical processes involved in the 1988 drought and 1993 floods in North America. *J. Climate*, **9**, 1288–1298, https://doi.org/10.1175/1520-0442(1996)009<1288:PPIITD>2.0.CO;2.

Trnka, M., and Coauthors, 2020: Czech Drought Monitor System for monitoring and forecasting agricultural drought and drought impacts. *Int. J. Climatol.*, **40**, 5941–5958, https://doi.org/10.1002/joc.6557.

United Nations Convention to Combat Desertification, 2022: Drought in numbers 2022. COP-15 Côte d'Ivoire, 51 pp., https://www.unccd.int/sites/default/files/2022-05/Drought%20in%20Numbers.pdf.

United Nations Economic and Social Commission for Asia and the Pacific, 2018: Ocean accounting for disaster resilience in the Pacific SIDS: A brief note for policymakers. Resilience Series—2018, 41 pp., https://www.unescap.org/sites/default/files/Ocean%20accounts_30Oct2018_LowRes.pdf.

Van Loon, A. F., and H. A. J. Van Lanen, 2013: Making the distinction between water scarcity and drought using an observation-modeling framework. *Water Resour. Res.*, **49**, 1483–1502, https://doi.org/10.1002/wrcr.20147.

——, and Coauthors, 2016: Drought in the Anthropocene. *Nat. Geosci.*, **9**, 89–91, https://doi.org/10.1038/ngeo2646.

Vanuytrecht, E., D. Raes, P. Steduto, T. C. Hsiao, E. Fereres, L. K. Heng, M. Garcia-Vila, and P. M. Moreno, 2014: AquaCrop: FAO's crop water productivity and yield response model. *Environ. Modell. Software*, **62**, 351–360, https://doi.org/10.1016/j.envsoft.2014.08.005.

Verbist, K., H. Maureira, and R. Aroche, 2018: *Atlas de la Canícula de América Central y el Caribe*. UNESCO Publishing, 46 pp.

Vergopolan, N., and Coauthors, 2021a: Field-scale soil moisture bridges the spatial-scale gap between drought monitoring and agricultural yields. *Hydrol. Earth Syst. Sci.*, **25**, 1827–1847, https://doi.org/10.5194/hess-25-1827-2021.

——, and Coauthors, 2021b: SMAP-HydroBlocks, a 30-m satellite-based soil moisture dataset for the conterminous US. *Sci. Data*, **8**, 264, https://doi.org/10.1038/s41597-021-01050-2.

——, and Coauthors, 2022: High-resolution soil moisture data reveal complex multi-scale spatial variability across the United States. *Geophys. Res. Lett.*, **49**, e2022GL098586, https://doi.org/10.1029/2022GL098586.

Walker, D. W., and A. F. Van Loon, 2023: Droughts are coming on faster. *Science*, **380**, 130–132, https://doi.org/10.1126/science.adh3097.

——, N. Jovanovic, R. Bugan, T. Abiye, D. du Preez, G. Parkin, and J. Gowing, 2018: Alluvial aquifer characterisation and resource assessment of the Molototsi sand river, Limpopo, South Africa. *J. Hydrol.*, **19**, 177–192, https://doi.org/10.1016/j.ejrh.2018.09.002.

——, and Coauthors, 2022: Drought diagnosis: What the medical sciences can teach us. *Earth's Future*, **10**, e2021EF002456, https://doi.org/10.1029/2021EF002456.

Wang, L., X. Yuan, Z. Xie, P. Wu, and Y. Li, 2016: Increasing flash droughts over China during the recent global warming hiatus. *Sci. Rep.*, **6**, 30571, https://doi.org/10.1038/srep30571.

Wang, S.-Y., J.-H. Yoon, R. R. Gillies, and C. Cho, 2013: What caused the winter drought in western Nepal during recent years? *J. Climate*, **26**, 8241–8256, https://doi.org/10.1175/JCLI-D-12-00800.1.

Ward, P. J., and Coauthors, 2020: Natural hazard risk assessments at the global scale. *Nat. Hazards Earth Syst. Sci.*, **20**, 1069–1096, https://doi.org/10.5194/nhess-20-1069-2020.

White, I., and T. Falkland, 2010: Management of freshwater lenses on small Pacific islands. *Hydrogeol. J.*, **18**, 227–246, https://doi.org/10.1007/s10040-009-0525-0.

Wilhite, D. A., M. V. Sivakumar, and R. Pulwarty, 2014: Managing drought risk in a changing climate: The role of national drought policy. *Wea. Climate Extremes*, **3**, 4–13, https://doi.org/10.1016/j.wace.2014.01.002.

Williams, G., 2013: Illegal sand mining dries up Shashe River. *Botswana Daily News*, 18 November, https://dailynews.gov.bw/news-detail/7138.

Yang, X., Y. Yang, Y. Tian, L. Liao, X. Xie, X. Mo, and L. Xiao, 2020: Characteristics of spatiotemporal distribution of rainfall-deficient flash drought in Guangxi (in Chinese). *Res. Soil Water Conserv.*, **27**, 149–157.

Yao, T., S. Liu, S. Hu, and X. Mo, 2022: Response of vegetation ecosystems to flash drought with solar-induced chlorophyll fluorescence over the Hai River Basin, China during 2001–2019. *J. Environ. Manage.*, **313**, 114947, https://doi.org/10.1016/j.jenvman.2022.114947.

Yuan, X., Z. Ma, M. Pan, and C. Shi, 2015: Microwave remote sensing of short-term droughts during crop growing seasons. *Geophys. Res. Lett.*, **42**, 4394–4401, https://doi.org/10.1002/2015GL064125.

——, L. Wang, P. Wu, P. Ji, J. Sheffield, and M. Zhang, 2019: Anthropogenic shift towards higher risk of flash drought over China. *Nat. Commun.*, **10**, 4661, https://doi.org/10.1038/s41467-019-12692-7.

——, Y. Wang, P. Ji, P. Wu, J. Sheffield, and J. A. Otkin, 2023: A global transition to flash droughts under climate change. *Science*, **380**, 187–191, https://doi.org/10.1126/science.abn630.

Zhang, B., F. Schilder, K. H. Smith, M. Hayes, S. Harms, and T. Tadesse, 2021: TweetDrought: A deep-learning drought impacts recognizer based on twitter data. *Proc. Tackling Climate Change with Machine Learning Workshop, ICML 2021*, Online, ICML, 32, https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1206&context=droughtfacpub.

Zhang, H., C. Wu, and B. X. Hu, 2019: Recent intensification of short-term concurrent hot and dry extremes over the Pearl River basin, China. *Int. J. Climatol.*, **39**, 4924–4937, https://doi.org/10.1002/joc.6116.

Zhang, M., X. Yuan, and J. A. Otkin, 2020: Remote sensing of the impact of flash drought events on terrestrial carbon dynamics over China. *Carbon Balance Manage.*, **15**, 20, https://doi.org/10.1186/s13021-020-00156-1.

Zhang, X., N. Chen, C. Hu, and X. Peng, 2018: Spatio-temporal distribution of three kinds of flash droughts over agricultural land in China from 1983 to 2015 (in Chinese). *Diqiu Kexue Jinzhan*, **33**, 1048–1057.

Zhao, T., and A. Dai, 2022: CMIP6 model-projected hydroclimatic and drought changes and their causes in the twenty-first century. *J. Climate*, **35**, 897–921, https://doi.org/10.1175/JCLI-D-21-0442.1.

Zhu, Y., Y. Liu, W. Wang, F. Yuan, M. Ma, G. Wu, and Y. Yin, 2021: Analysis of spatio-temporal characteristics of flash drought and slowly-evolving drought using soil moisture percentile. *Nongye Gongcheng Xuebao*, **37**, 114–122.