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Identification, physical mechanisms and impacts of drought–flood abrupt alternation: a review

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Climate change has led to an increase in the frequency of extreme events, such as droughts and floods. This study aims to review the literature on the newly proposed phenomenon known as drought-flood abrupt alternation (DFAA). A comprehensive summary is provided to round up the numerous approaches employed to identify DFAA events, as well as its mechanisms and impacts. To provide a reference for responding and managing the emerging intensity and frequency of DFAA events, we conclude the paper by listing the insufficiency of current research and suggesting possible future research directions. As for the impact of DFAA, besides the loss of life and property which can be caused by any natural disaster, a DFAA event severely threatens food security by making a lasting and profound impact on the land productivity through the alteration of the combining conditions of water, soil, and temperature. As for the future research directions, existing indexes developed for DFAA identification should be improved by downscaling the temporal and spatial scale, with interactions of neighboring drought and flood events taken into consideration. What's more, to better protect human society from the losses caused by DFAA, researches on accurate DFAA prediction are encouraged.

KEYWORDS

DFAA, RDFAI, DWAAI, physical mechanism, food production

Introduction

Floods and droughts are not only the most commonly occurring natural disasters globally (Bola et al., 2014; Yu et al., 2014; Daryanto et al., 2015; Amrit et al., 2020; Hameed et al., 2020; Global Natural Disaster Assessment Report, 2021; Han et al., 2021), but also the natural disasters causing the most significant damage to the economy, human life, and agricultural production. Floods and droughts have thus been the focus of extensive research in hydrological science, covering the occurring patterns, causes, and impacts (Samuel & Sivapalan, 2008; Apurv & Cai, 2020; Mtewele et al., 2021).

Climate change and intensive human activities have highly disrupted global circulation systems and led to a radical change in the pattern of extreme precipitation during the 21st century. The frequency and intensity of floods and droughts have therefore increased alarmingly, while the duration and timing of these events have become more unpredictable (Jhong & Tung, 2018; Lehner et al., 2006; Zhang & Cong, 2014; Duan et al., 2022). An

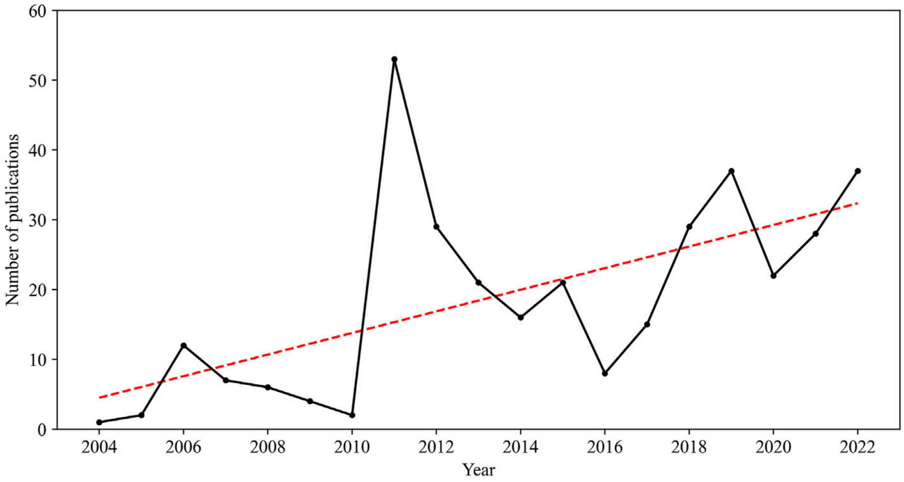

FIGURE 1
Tendency of publications on DFAA topic.

increase in drought occurrence has been explored worldwide, like in the Amazon Basin, India, North America, Africa, and Asia (Duffy et al., 2015; Duan et al., 2016; Xu et al., 2019; Miao et al., 2020). Meanwhile, the return period of a fixed flood magnitude has descended significantly over the last two decades. A 50-year flood flow before the 20th century may have decreased to a 20 or 5-year flood (Latif & Mustafa, 2020). What's more, the pattern of flood timing within a year has become ambiguous due to early snowmelt or the increasing occurrence of extreme rainstorms (Yu et al., 2021; Singh et al., 2022).

Under these circumstances, floods and droughts, which were considered as separate disasters, have now tended to emerge into one phenomenon. It is called drought-flood abrupt alternation (DFAA) (or dry-wet events) and refers to the rapid shift between floods and droughts within a year. For example, the downstream of Pearl River Basin in South China, where Hong-Kong and Macao are located, had just ended year-long drought (from Oct. 2020 to Apr. 2022) before it abruptly had a flood with a 100-year recurrence period (Jun. 2022).

A storm surge coinciding with extreme flooding in a delta area can lead to regional flooding; heavy rain combined with earthquakes can trigger landslides (Yang et al., 2010; Bai et al., 2013). Multi-hazard events can always undoubtedly induce greater loss in economy and life than just a single disaster. And just like any other multi-hazard event, a DFAA can pose a greater threat to eco-environment, social and humanistic systems than a single flood or a drought event (Zhou & Liu, 2018; De Luca et al., 2020; Xue et al., 2022). To keep up with the increasing frequency of DFAA occurrence, more researchers have put great effort in the study of DFAA (Tang & Shao, 2007; Wang et al., 2012; Xiong W. et al., 2017a; Yang, et al., 2019a; Qin et al., 2019; Wang J. H. et al., 2021a; Gao & Zhao, 2022). Tendency of publications on DFAA topic is shown in Figure 1.

In order to protect human society from DFAA and to set up emergency plans for DFAA, current studies have tried to explore the generation, pattern and impact of DFAA (Wu et al., 2006; Shan et al., 2015; Chen et al., 2020; Bi et al., 2021; Ford et al., 2021; Yu et al., 2021; Ansari & Grossi, 2022). To study the generation of DFAA events, the physical mechanism needs to be analyzed on the basis of the precise definition and extraction of a DFAA event. Also, the temporal or spatial pattern of DFAA can be easily explored once the events themselves can be extracted efficiently from available recording data. Besides, as the basis of a scientific issue, it is of first priority to set up the definition of the phenomenon studied. Therefore, this review starts from the definition of DFAA and the indexes used to refer to a DFAA event.

Since the patterns of DFAA events differ from country to country, area to area, and the results generated in previous works can hardly be of any reference to researches afterward once the study area is changed, the topic of DFAA is not combed through in this paper. As for the impact of DFAA, its major strike on human society is the impact on the eco-environmental system, especially on the aspect of soil productivity and food production (Pan et al., 2022). Therefore, the progress in exploring the eco-environmental impact of DFAA is covered in this review.

Meanwhile, although the forecast and prediction of DFAA events has numerous significance for setting-up disaster-protection policies, this topic is not covered in our paper due to the fact that little quantity of work related is done. Overall, this review covers the current research on DFAA. In particular, it focuses on three key aspects: 1) the definition of DFAA and the indexes constructed to indicate DFAA; 2) the physical mechanisms of DFAA; and 3) the eco-environmental impact of DFAA. We then conclude the paper by detailing the gaps in the current research and propose possible directions for future work.

Defining the drought–flood abrupt alternation

In previous researches, there have been two terms referring to the phenomenon of the abrupt transition between floods and droughts: one is “drought-flood abrupt alternation” and another is “dry-wet events” (Yang, Weng, et al., 2019b; Wang Y. et al., 2021b). And between these two terms, drought-flood abrupt

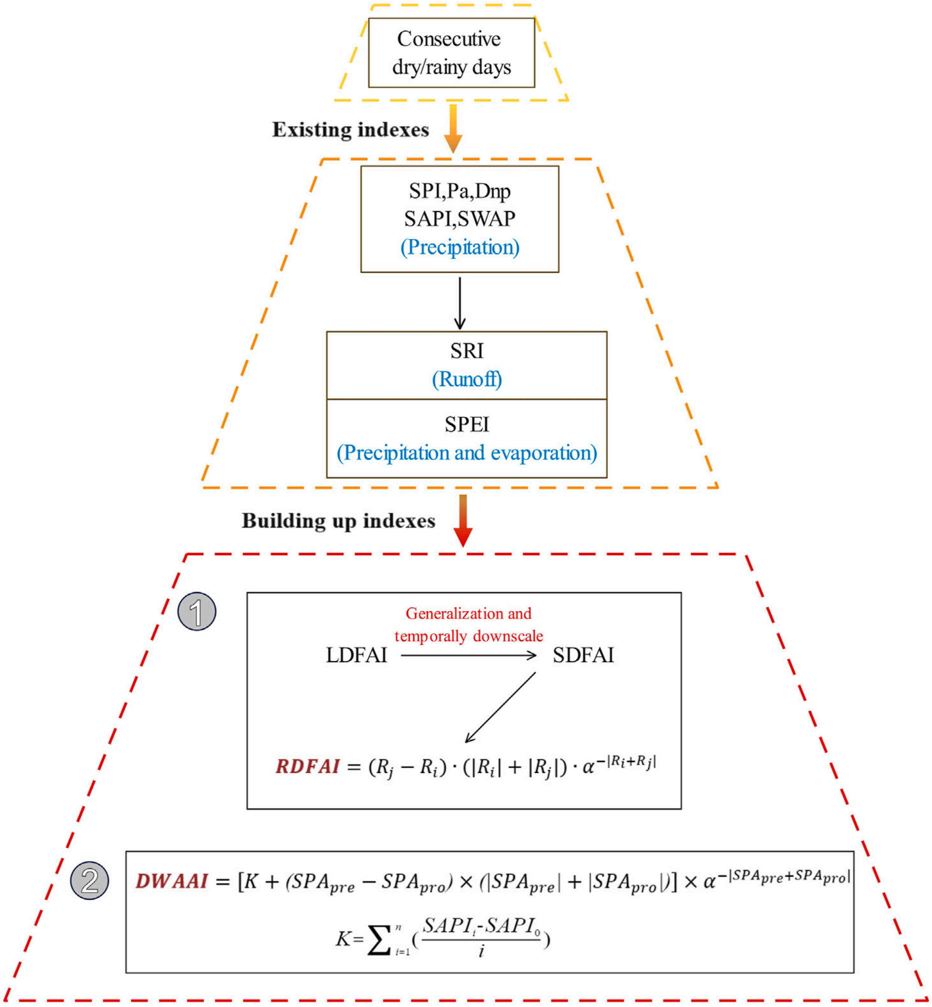

FIGURE 2
The progress of the index used to extract DFAA events from historical records.

alternation has been used extensively (more than 80% of the papers that we have reviewed choose to use it). Compared to "drought-flood abrupt alternation", "dry" and "wet" used in "dry-wet events" lacks clarified boundaries to define the intensity of dry or wet. Therefore, although no discussion has been made on the naming of this phenomenon, we have applied the term "drought-flood abrupt alternation" (DFAA) to depict the situation that a flood and a drought happened closely in time in the same area.

Although the number of studies related to DFAA has increased over the past 7 years, the blank of a unified definition of DFAA has not yet been filled up (Bi et al., 2021). This review does not aim to give a certain definition. However, it can be generated from existing works on DFAA, in order to define an event of DFAA, three aspects have to be settled: 1) the direction of the abrupt turn, i.e., whether it is turning from flood (wet) to drought (dry), or from drought (dry) to flood (wet); 2) the number of abrupt turning times in one event, for example, a "flood-to-drought" (FTD) or a "drought-to-flood" (DTF) event contains one abrupt turn, and a "flood-to-drought-to-flood" (FDF) or a "drought-to-flood-to-drought" (DFD) event contains two (Ma, Yang, et al., 2019; Shi et al., 2021); 3) the length of time range of the abrupt turn within a DFAA event. Most existing researches consider a realm of four to 6 months to be a common time span for a FTD/DTF shift (Wu et al., 2006; Shan et al., 2015).

The multiple definitions of DFAA have resulted in numerous approaches for the construction of indexes that indicate and identify DFAA from historical records. For instance, indexes have been proposed using Standardized Precipitation Index (SPI) or Palmer Drought Severity Index (PDSI) for various time scales, such as days or months (Wu, 2006). Additionally, the frequency of DFAA events under a fixed time span varies with the climate features and regions. Thus, defining an index that can be used in both (semi-)arid and (semi-)humid areas, or that fits both Mediterranean and subtropical monsoon climate zones, proves to be a complicated task.

Identifying drought–flood abrupt alternation with existing indexes

Of all the studies reviewed in this paper, which were all published in journals related to hydrology and natural hazards, over 66.7% works covered the issue of DFAA identification. Building an index to identify a DFAA event is the basis for research on other aspects of DFAA. It not only helps turn a natural phenomenon into a theoretical concept explicitly defined, but also presents this concept as a quantifiable formula. It provides a tool to analyze the recorded data and recognize historical DFAA events, allowing for the temporal and spatial patterns of DFAA events to be further explored. Similarly, building an index facilitates the investigation of the physical mechanisms and impacts of DFAA. The progress of the index used to extract DFAA events from historical records is shown in Figure 2.

The initial identification of DFAA was developed solely according to precipitation or the number of days of precipitation, with droughts and floods generally selected independently. The droughts were then rated by the number of consecutive dry days, while the floods by the intensity of the initial rain or the precipitation under various rainfall scenarios (Bi et al., 2019; Liu, 2019; Wang et al., 2019). DFAA events were subsequently identified with statistical methods such as the run-length theory (Tang & Shao, 2007; Xiong Q. et al., 2017b).

Following the previous research, tools to recognize DFAA events were improved by applying existing indexes such as the SPI and the percentage of precipitation anomalies. The method of applying existing indexes is straightforward to understand and the required data can be obtained easily. The indexes in these studies were first calculated on a monthly or seasonal basis, and threshold values for different ranks of DFAA events were then set accordingly. DFAA events of different ranks could therefore be easily captured by comparing the index values with the threshold values (Chen et al., 2020; Gao & Zhao, 2022). Zhang and Li (2019) extracted DFAA events recorded in the Pacific West Bank between April and September of every year for more than a decade using the SPI. The results were in accordance with those extracted by the percentage of precipitation anomalies.

The SAPI (standardized antecedent precipitation index) has also been employed to determine the timing of precipitation when selecting DFAA events. For example, Yang et al. (2021) calculated the cumulative precipitation volume for no more than 100 days, which was then used to generate SAPI thresholds to classify droughts and floods. The results were in agreement with the recognition of DFAA under a seasonal time scale (Wang et al., 2012; Yang, et al., 2019c).

Several studies have introduced the percentage anomaly (Pa) of precipitation and the continuous days without available precipitation (Dnp) into the identification of DFAA (Qin et al., 2019; Zhang et al., 2019; Wang J. H. et al., 2021a). However, the number of case studies is not sufficient to test the representativeness and stability of this index.

Additional existing indexes have also been used to detect DFAA events. For example, Zhao et al. (2020) and Yang, Chen, et al. (2019a) employed the standard runoff index (SRI) and standardized weighted average precipitation (SWAP) to determine the temporal and spatial patterns of DFAA events in Hanjiang River Basin. Results showed that, compared with applying SPI simply, SWAP and SRI can better reflect elements such as the intensity of a drought, the duration and the intensity of a flood, and the turning point of DTF/FTD abrupt alterations.

DFAA can be easily identified by using just a single meteorological factor as precipitation. However, the features of drought are not fully reflected in these studies as other relevant elements, such as evaporation, are ignored. Several scholars have adopted both precipitation and air temperature to indicate a DFAA event, improving the method by replacing SPI with SPEI (standardized precipitation-evapotranspiration index). Zhen et al. (2023) calculated SPEI for monthly, seasonal, and annual scales to extract DFAA events in inland Eurasia, and the reliability of these results were tested by comparing them with historical records.

Identifying drought-flood abrupt alternation by building up indexes

Runoff drought-flood abrupt alternation index (RDFAI)

Gradually, new indexes have been specifically proposed to identify DFAA. The indexes most widely adopted are the runoff drought-flood abrupt alternation index (RDFAI) and the Dry-Wet Abrupt Alternation Index (DWAAI). RDFAI contains both the long-cycle drought-flood abrupt alternation index (LDFAI) and the short-cycle drought-flood abrupt alternation index (SDFAI). In these indexes, DFAA is identified as an integrated event rather than a composition of two neighboring flood or drought events. The intensity and time scale of a DFAA are both shown in one index. LDFAI was first proposed among these indexes by Wu et al. (2006) for the lower Yangtze River area, where the monsoon climate dominates and over 60% of precipitation concentrates in summer (May to August). The index considers both FTD and DTF, and it can be calculated as follows,

$$\mathrm{LDFAI} = (R_{78} - R_{56}) \cdot (|R_{56}| + |R_{78}|) \cdot 1.8^{-|R_{56}+R_{78}|}$$

where R_{78} refers to the SPI during July and August; R_{56} is the SPI during May and June, when $R<0.5$, it refers to drought and when $R \geq 0.5$, it refers to flood; $(R_{78} - R_{56})$ indicates the intensity of the abrupt alteration; $(|R_{56}| + |R_{78}|)$ indicates the joint intensity of flood and drought; and $1.8^{-|R_{56}+R_{78}|}$ is the weighting coefficient, which is set to reduce the weight of a single flood or drought event while increasing the weight of a DFAA event. In order to fit for different climates in different areas, the weighting coefficient is not a fixed value. As in Lu (2009), 0.9 was found to be more appropriate for the Mississippi Valley.

LDFAI is an easily-built and quantifiable index and has thus been used to identify DFAA in sub-tropical monsoon, mountain, and Alpine mountain climate areas (Sun et al., 2017; Zhen et al., 2021). However, studies using LDFAI generally focus on selecting DFAA events occurring between April and September. Moreover, application of LDFAI has not significantly improved the recognition effect compared to SPI. Previous work has also revealed an increase in uncertainties with LDFAI (Shan et al., 2015; He et al., 2016; Bai et al., 2019).

Along with the application of LDFAI in different regions, the numbers used in the original formula to refer to different months have been conceptualized to only represent the months before or after the alteration point. In the original formula, R_{78}=SPI in July and August, in the improved formula, R_j=SPI in months that are after the turning point (abruption timing) from drought to flood or

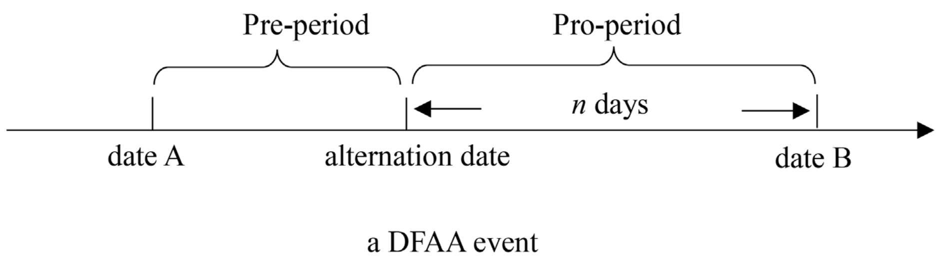

FIGURE 3
Demonstration of a DFAA event.

flood to drought, j can refer to more months other than just July and August (Yuan et al., 2021). Similarly, R_{56} in the original formula has been improved to R_i referring to the months before the turning point.

Inspired by LDFAI, Zhang et al. (2014) proposed SDFAI, which is calculated as follows,

$$\mathrm{SDFAI} = \left(R_j - R_i\right) \cdot \left(|R_i| + |R_j|\right) \cdot 3.2^{-|R_i + R_j|}$$

where 3.2 is the weighting coefficient generated and tested by setting j and i as 8 and 7 (or 7 and 6, or 6 and 5).

Compared to LDFAI, SDFAI narrows down the time scale from neighboring seasons to neighboring months by keeping the basic structure of LDFAI and changing only the weighting coefficient. SDFAI is able to better identify a DTF compared to LDFAI (Sun et al., 2012). Thus, LDFAI and SDFAI have been combined and considered as the long-and-short-cycle runoff drought-flood abrupt alternation index (RDFAI) (Fan et al., 2019). When RDFAI is greater than 1, it represents a DTF event, and when RDFAI is smaller than −1, it indicates a FTD event (Bi et al., 2021).

Dry-wet abrupt alternation index (DWAAI)

Based on RDFAI, Shan et al. (2018) proposed a DFAA index at the daily scale known as the dry-wet abrupt alternation index (DWAAI), based on the following formula:

$$\mathrm{DWAAI} = \left[K + \left(\mathrm{SPA_{pre}} - \mathrm{SPA_{pro}}\right) \times \left(|\mathrm{SPA_{pre}}| + |\mathrm{SPA_{pro}}|\right)\right] \times a^{-|\mathrm{SPA_{pre}} + \mathrm{SPA_{pro}}|}$$

$$K = \sum_{i=1}^{n} \left(\frac{SAPI_i - SAPI_0}{i}\right)$$

where $\mathrm{SPA_{pre}}$ and $\mathrm{SPA_{pro}}$ are the standardized precipitation anomalies calculated respectively before and after the DTF alteration; $SAPI_i$ and $SAPI_0$ refer to the standardized antecedent precipitation index (McQuigg, 1954) on the ith day after and the last day before the alteration date, respectively; and n is the number of days during the period after the alteration date, i.e., Pro-period. Demonstration of a DFAA event is shown in Figure 3.

DWAAI further narrows down the time scale to days, and improves the extraction efficiency of DFAA events, particularly for those events less than a month. However, in Shan's work, only DTF events were considered, and DWAAI was tested in a subtropical humid area. Previous research also claims that dry-wet abrupt alternations generally occur in (semi-)humid, subtropical humid, and tropical humid regions (Chen et al., 2020; Zhao, Deng, et al., 2022a). Wang et al. (2020) used DWAAI to select both the DTF and FTD events in the Poyang Lake area by applying a 52-year data record (from 1960 to 2012). The value of weighting coefficient 'a' in the formula of DWAAI was determined to be highly empirical, affected by the local climate characteristics and the temporal scale of the research. More specifically, high uncertainties exist in the calibration of "a" in different river basins. Future work should investigate the impacts of the value of "a" on the selection of DFAA.

The detection of DFAA requires further research, irrespective of whether new or existing indexes have been used. There is no unified approach for different areas under various spatial and temporal scales, and the uncertainties and sensitivity remain to be comprehensively tested. In the following, we describe several key aspects that require future work and research.

First, indexes such SPI, RDI, and SPEI are not completely independent (Bi et al., 2019; Bonsal et al., 2011; Zhao et al., 2020). How to select existing indexes, and how to differentiate results generated by different yet correlatively related indexes remains to be determined.

Second, the applications of RDFAI and DWAAI are limited in the temporal scale and can be further tested in different river basins across the globe. The number of DTF and FTD occurrences are usually not even within 1 year or a time interval of measurement. In the space of 1 year or more, if DTF happens once, maybe FTD does not happen at all or happens twice or three times. Thus far, these indexes are more commonly applied in humid regions, where FTD occurs more frequently than DTF. Therefore, there is a gap in the application of RDFAI and DWAAI in more arid/semi-arid areas. In addition, whether RDFAI and DWAAI can efficiently detect DFAA in the months from October to March also needs to be verified (Liang et al., 2022). Current indexes cannot fully indicate DFAA without considering its spatial pattern, which can easily lead to missing DFAA events in small areas (Tu et al., 2022).

Third, current research generally takes precipitation as the sole element when defining DFAA. Despite limited studies considering several characteristics (e.g., temperature), other elements such as previous soil moisture content and land use, which can affect the generation of DFAA events, are rarely included. Thus, future research should determine the major indicators for DFAA and how to build an index using these indicators while controlling the uncertainties via calibration. In addition to precipitation indexes, previous studies have also attempted to identify DFAA

TABLE 1 Features of different indicators used in DFAA identification.

Category	Indicator	Meteorological factors taken into consideration	Historical records required	Detecting efficiency	Applied scale (temporal and spatial)
Directly from measurement data	Consecutive dry/rainy days (with intensity of initial rain under consideration)	precipitation	Multi-annual daily precipitation	-	Multi-annual and annual, on spot
Based on existing indexes	SPI	precipitation	Multi-annual daily precipitation	= PA	Seasonal (Apr.-Sep.), region/river basin
	Pa (percentage of precipitation anomalies)			= SPI	Seasonal (Apr.-Sep.), region
	Dnp (continuous days without available precipitation)			-	Multi-annual and annual, region
	SAPI (standardized antecedent precipitation index)			-	Seasonal, region
	SWAP (standardized weighted average precipitation)			>SPI	Seasonal (Jun.-Oct.), region/river basin
	SRI (standard runoff index)	runoff	Multi-annual daily runoff	>SPI	Seasonal, region/river basin
	SPEI (standardized precipitation-evapotranspiration index)	precipitation and evapotranspiration	Multi-annual daily precipitation, temperature (average, maximum, minimum), sunshine duration, relative humidity	-	Seasonal and annual, region
Building up indexes specifically for DFAA	LDFAI (long-cycle drought-flood abrupt alternation index)	precipitation	Multi-annual daily precipitation	>SPI (highly dependent on the coefficient; efficient for DTF events)	Seasonal (May. to Aug.), region/river basin
	SDFAI (short-cycle drought-flood abrupt alternation index)			>SPI (highly dependent on the coefficient; efficient for DTF events)	Seasonal (Apr. to Sep.) and annual, region/ river basin
	DWAAI (Dry-wet Abrupt Alternation Index)			efficient for DTF and FTD events	Within a month, region/river basin

In the array of "Detecting Efficiency", i.e., the efficiency of detecting DFAA events with a certain indicator, "-" means it has no reference to define its efficiency, and it is unknown whether it is higher or lower than other indicators.

using existing drought indexes, including the aggregate drought index (ADI), temperature soil moisture precipitation drought index (TMPDI) and palmer drought severity index (PDSI). Compared with SPI, PDSI has the advantage of attaching the importance to the impact of evapotranspiration on the soil moisture deficit, and an improved version of PDSI, namely, the self-calibrating palmer drought severity index (scPDSI) has been developed. The advanced application of these indexes in DFAA identification is reserved for future research, and the theory of constructing such indexes can provide a reference for building an ideal DFAA index. The advantages, disadvantages, sphere of application of different indexes used to identify DFAA event are summarized in Table 1.

Analyzing physical mechanisms of DFAA

Numerous studies have investigated the physical mechanisms and impact of DFAA events (Bi W. X. et al., 2019; Gao Y. et al., 2019; Bi W. et al., 2020; Yuan Y. et al., 2021).

A persistent lack of rainfall leads to a drought, while a storm or continuous precipitation leads to flooding. The generation of a DFAA event is the abrupt alteration between these two scenarios and is therefore highly related to the local precipitation, namely, the hydrological cycle (Yu et al., 2021). The most straightforward approach to discover the physical mechanisms is to detect the relationship between the DFAA and the indexes of rainfall, such as SPI and Pa (Bai et al., 2019; Xie et al., 2021; Zhang et al., 2022).

For example, Li et al. (2017) analyzed the characteristics of the April-to-June rainfall with a return period between 10 and 20 days. Time-lagged cross-correlation analysis was carried out to detect the relationship between 10 and 20 days rainfall and DFAA. Zhao, Deng, et al. (2022b) and Tang et al. (2021) compared the spatial and temporal patterns of precipitation and DFAA events, revealing the degree of precipitation concentration to be a key factor triggering DFAA. By detecting DFAA with SPEI, Qiao et al. (2022) demonstrated the duration, intensity, return period, and temporal and spatial pattern of DFAA; and analyzed abrupt alterations in rainfall and evapotranspiration. They concluded that the imbalance

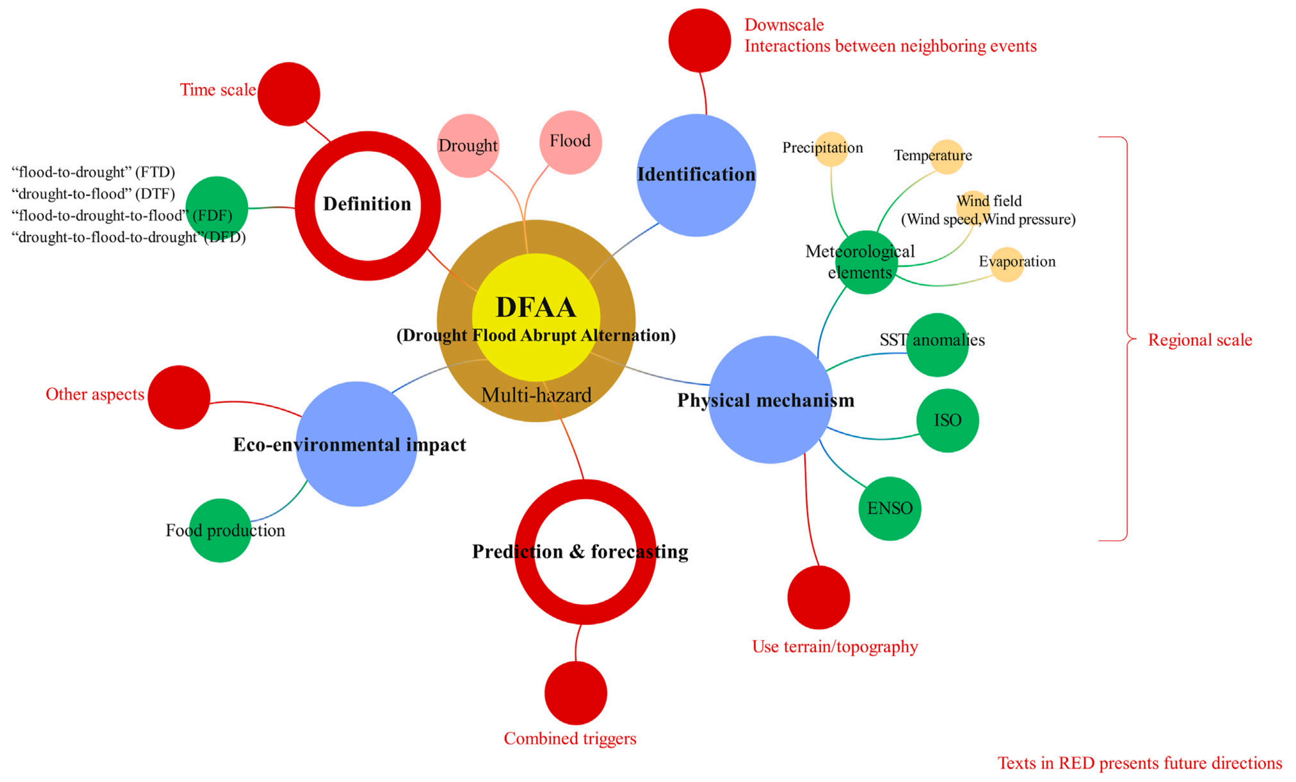

FIGURE 4
Structure of present researches and proposed future directions.

in regional water vapor was the major driving factor for the abrupt alteration from flood to drought or drought to flood in a DFAA event.

Investigating how the local water cycle alters precipitation can provide us with a deeper understanding of DFAA mechanisms. For example, Yu et al. (2021) focused on the water vapor budget and the transformation of the water vapor transport channel, while Li et al. (2017) explored the water vapor source region and water vapor transport channel to determine the potential connection between the water cycle and DFAA.

However, precipitation alone cannot fully explain the physical mechanisms of DFAA events. Therefore, along with the development of research, several scholars have included meteorological factors such as atmospheric temperature and wind speed to depict the generation process of DFAA (Chen et al., 2020). Previous studies have employed regression methods (e.g., the enhanced regression tree) to detect the driving factors of DFAA, identifying elements such as precipitation, evaporation, wind speed (wind field, wind pressure), temperature, moisture, etc., (Yuan et al., 2021; Zhang et al., 2021).

Several scholars have combined precipitation, temperature, wind speed, and other meteorological factors as the embodiment of certain weather events (including sea surface temperature (SST) anomalies) or the local reflection of the macro-scale circulation phenomenon such as atmospheric intra-seasonal oscillations (ISO) or the El Niño-Southern Oscillation (ENSO) (Feng et al., 2012; Shen et al., 2012; Li et al., 2014; Shan et al., 2018; Wang, Xiao, et al., 2021a; Yu et al., 2021; Zhen et al., 2021; Zhao, Zhang, et al., 2022a). Current work has reported that DFAA events in the Pacific West Bank are closely related to astronomical phenomena such as sunspot bursts and large-scale circulations including air-sea interactions in the tropical Indian Ocean, the summer monsoon in the South China Sea, western Pacific subtropical high air pressure, western pacific warm pool, the enhancement of the East Asian trough, the thermal effect of Qinghai-Tibetan Plateau, and ENSO (Zheng et al., 2017; Yuan et al., 2021; Zhang et al., 2021).

In addition to the atmospheric circulation and sea temperature anomalies, other environmental factors such as regional topographical conditions, low-frequency circulations, and hydraulic engineering conditions are reported to affect the formation of DFAA events (Tang & Shao, 2007; Zhang et al., 2007; Wang et al., 2019). The conclusions on the generation of DFAA provide a theoretical basis for the prediction of DFAA through coupling with the GCM (Global Climate Model) data, among which RCPs climate scenarios (a series of integrated enrichment and emission scenarios) are used as input to GCM.

Exploring the eco-environmental impact of DFAA

The impact of DFAA is discussed under the realms of disaster protection, the local environment, and biological systems. As food is the key factor to social security and stability, and the "water-energy-food nexus" is one of the most important issues in hydrological sciences (IHAS), determining the impacts of DFAA events on food production and the crop growing environment has attracted much attention (Yu et al., 2014; Daryanto et al., 2015; Ma, Weng, et al., 2019; Bi et al., 2021). The impact of DFAA on essential elements for grain production, such as water, soil, and temperature is both direct and intense. Current research has selected indicator factors such as soil moisture, soil microorganisms, soil salinization, land degradation, and soil erosion to discuss the DFAA impact on soil (Gao & Zhao, 2022). Research on land productivity reduction after DFAA can be differentiated according to the crop type (generally maize or rice). The time scale for such research can be seasonal (e.g., summer maize) or yearly (Bi et al., 2020).

Due to its extreme sensitivity to the combination of water and temperature, rice is the crop type mostly affected by DFAA. Thus, rice has become a major research object, particularly in countries that mainly consume rice (Xiong, Shen, et al., 2017a; Yan & Chen, 2013). Scholars have selected the characteristics of roots, leaves, yield, and grain quality to represent the physiological properties of the affected rice (Bi et al., 2020). By detecting the change trends of these properties, the impact of DFAA on rice production is analyzed. In order to investigate the correlation between DFAA and rice production changes, and to further quantify the impact of DFAA on rice, Chen et al. (2018) employed the Hydrus model to simulate the process of DFAA in irrigated areas and the Jensen model to simulate the reduction in rice production. Their study provides a reference for further research on quantifying the impact of DFAA on rice production at the microscopic scale.

The results of the current research reveal that in general, DFAA has a greater impact on yield compared with a single flood or drought event. In particular, yield is affected the most greatly by DFAA, followed by drought, and subsequently by flood (Gao et al., 2019). Despite the impact of DFAA on the local bio-environment system, the feedback of different bio-environment systems with varying land use types can also act towards the process of DFAA. For example, Wang et al. (2019) discovered that after a DFAA (flood-to-drought) happened in three regions, respectively dominated by shrubs, grasslands, and wetlands, the temperature after a drought is usually high, and the temperature decreased faster in shrubs > grasslands >wetlands. Future work should investigate how this interaction may reinforce or trigger a DFAA event.

Discussion and conclusion

This review rounds up the approaches developed to identify a drought-flood abrupt alternation event (DFAA), as well as the corresponding physical mechanisms and impacts of a DFAA. Based on the comprehensive review, several directions for future research are proposed. Structure of present researches and proposed future directions is shown in Figure 4.

First, the definition needs to be settled, by answering the questions that have been listed in the second section of this review. Meanwhile, the issue of time scale does not only exists for the definition of DFAA, but also for the identification of DFAA by building up indexes, RDFAI and DWAAI are two widely used and soundly developed indexes for identifying a DFAA event. The uncertainty of applying these indexes highly lies in the calibration of the contained weighing coefficients, which is relevant to the temporal scale of the DFAA event intended to be detected. In existing works, the establishment of RDFAI is based on the assumption that a DFAA event occurs in the summer (from April to September in a monsoon climate area). However, a flash flood following a drought in winter (or dry spell) can also lead to a DFAA (DTF) event. Therefore, RDFAI should be improved so that it can be applied in different areas on an annual scale.

In addition to the issue of temporal scale, the spatial scale of indexes being built up and applied also needs to be further studied. In the literature, the smallest spatial scale on the formation of a DFAA event is a large river basin, covering different types of land use (e.g., smaller water basin, city and rural areas) at the same time. DFAA events may happen on a smaller spatial scale. Research on the formation of DFAA events has encountered challenges in downscaling limits for the spatial scale. Physical mechanisms are largely discussed on a regional basis. However, the formation of DFAA in a watershed basin is not well studied, nor is the impact of terrain/topography and land use on a local DFAA. Therefore, how to downscale is a future direction in the aspect of DFAA identification.

Furthermore, the DFAA identification results based on the RDFAI/DWAAI or the simple SPI do not differ substantially because they are all based on the data of precipitation. Existing discussion on additional contributing factors other than precipitation is not adequate. Whether it is warranted to develop additional indexes specifically for DFAA identification should thus be discussed.

Moreover, neighboring drought and flood events may not be entirely independent according to current research on the physical mechanisms of DFAA events. Therefore, to identify a DFAA event, future research on DTF and FTD events should account for the interactive relationship between neighboring drought and flood events.

As for the impact study of DFAA, current researches have discussed the impact of DFAA events on soil characteristics, rainfall, and regional vegetation, with the majority of studies investigating the impact on food production. Future work should explore the effects of DFAA on other eco-system environments, as well as urban infrastructures including flood-preventing engineering projects.

As for the generation of a DFAA, or to say, the physical mechanism of a DFAA, existing works mainly focused on the direct influence of meteorological elements or anomaly climatic events, few considered the connection between the regional feedback after the abrupt alternation within a DFAA period and the occurrence of the next phase of this DFAA event. Judged from this perspective, future researches can examine whether specific areas with a particular combination of vegetation, land use, and climate features can trigger and intensify DFAA events and the interaction between these elements and DFAA events.

In addition to the dimensions of DFAA covered in this review, there are other branches of DFAA with too few works to be reviewed in this paper but are of enormous value and waiting to be further explored. Technique for the forecasting and prediction of DFAA is one of these branches. It is key to determine effective strategies for DFAA events. Attempts have been made to forecast DFAA events based on the Global Atmospheric Model (GCM) under different RCPs and WRF models integrated with PRISM (Yang, Weng, et al., 2019b; Chen et al., 2020). Future research is required to enhance the accuracy of prediction on the regional, catchment, and city scales.

Author contributions

XB: Conceptualization, Resources, Writing-original draft preparation, Writing-review and editing, Funding acquisition. CZ: Project administration, Supervision, Writing-review and editing. YT: Conceptualization, Resources, Writing-original draft preparation, Writing-review and editing. ZZ: Writing-review and editing. BY: Writing-original draft preparation. ZW: Writing-original draft preparation. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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