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Review article

Responding to climate services in the context of drought: A systematic review

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HIGHLIGHTS

- Our systematic review synthesises responses to drought-related climate services (CS).
- Half of the CS users identified with our literature review are farmers.
- Responses by farmers to CS were mainly changing crops and crop calendars.
- Responses by non-farmer were mainly to develop or enact plans, policy and programmes.
- We find research gaps in changes in perceptions, attitudes and resulting impacts.

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ABSTRACT

Climate Services (CS) are increasingly being employed to address challenges resulting from climatic hazards. Research has focused on identifying and categorising CS, CS uptake, barriers to use, and CS user needs. Findings on empirical responses to CS are scattered. The aim of this paper is to systematically review existing literature on behavioural, perception, and attitude responses to CS, in the context of drought. Our review considers CS responses explicitly and is not limited to specific user groups or regions. Using the Web of Science database, we identified 88 journal articles containing terms related to CS, behaviour and droughts, published between 1999 and 2022. We identified and classified the characteristics of the CS, responses to CS, and the impacts that these responses had. We find that behavioural responses are reported more frequently than attitude and perception responses to CS. Half of the CS users consisted of farmers, mostly provided with seasonal forecasts, who respond to the CS information predominantly by changing crops or crop planting/harvesting dates. Non-farmers responded to CS behaviourally by enacting or developing plans, policies, or programs. This overview provides an evidence base towards the assessment of impacts of CS, and suggests that further developing CS could require a shift from providing precise climate or weather data, towards providing how climate or weather information relates to the decision-spaces of users.

Introduction

Climate services (CS) are increasingly relied upon to adapt to climate change, because of the rising recognition of the need for adaptation, as well as significant technological advancement resulting in more available and better-quality climate data (Vaughan and Dessai, 2014; Brasseur and Gallardo, 2016; IPCC, 2021). According to Vaughan and Dessai (2014), CS involve '*the generation, provision, and contextualisation of information and knowledge derived from climate research for decision making at all levels of society*'. For instance, CS could entail the provision of timely, relevant and accessible weather forecasts to farmers, who based on this information, choose to plant drought resilient crops.

Due to the growing potential and use of CS, research efforts to understand the CS user experience and improve CS have increased, but empirical research on responses to CS by users is scattered (Tall et al., 2018). Existing research on CS has focused on identifying and categorising the existing CS landscape (Cortekar et al., 2020; World Meteorological Organization, 2020; Visscher et al., 2020), identifying CS uptake and barriers of use (Soares and Dessai, 2016; Gumucio et al., 2020; Perrels, 2020), and identifying CS users' needs (Sultan et al., 2020; Tart

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et al., 2020), or touching upon several of these themes (Brasseur and Gallardo, 2016; Vaughan and Dessai, 2014; Hewitt and Stone, 2021). Furthermore, research aims to understand changes in economic impacts of decisions due to CS, rather than evaluating how CS affect the process of changing perceptions, attitudes and observable behaviour (Findlater et al., 2021; Tall et al., 2018; Nkiaka et al., 2019; Suckall and Soares, 2022).

Existing reviews on the evaluation of CS not only fail to explicitly consider the responses to CS, they also often remain restricted to specific user groups or geographic areas. Additionally, responses to CS are only considered as a means to evaluate how CS value has been determined. For example, Tall et al. (2018) review methodologies used to identify CS value to agricultural outcomes (e.g. community development or farmer livelihood improvement) considering only rural agricultural CS users in Africa. Nkiaka et al. (2019) broaden the number of CS users reviewed by synthesising CS needs of farmers, water managers and disaster managers, in Sub-Saharan Africa. Yet CS responses are implicitly considered with the primary purpose of evaluating CS user needs. The value of CS has also been systematically reviewed in a South Asian context, however here CS responses are again considered only implicitly (Suckall and Soares, 2022). Suckall and Soares (2022) do not limit their systematic review to particular CS users, however, they do not include studies on empirical responses to hypothetical CS, or responses to CS in an experimental setting. Additionally, they also only consider perceptions in terms of increased awareness and understanding the threats posed by climate change.

Besides the directly observable responses to CS (behavioural responses), CS users' attitudes, perceptions and the heterogeneity thereof, are increasingly recognised for their role in adaptation to climate hazards (Steynor et al., 2021; Steynor and Pasquini, 2019; Deryugina, 2013; Cameron, 2005), yet these are often overlooked (Dang et al., 2019; Grothmann and Patt, 2005; Kuehne, 2014; Goebbert et al., 2012). To our knowledge, there are no reviews of changes in people's perceptions and attitudes due to CS. Perceptions and attitudes have mostly been considered in a specific hazard setting without connection to CS (Foguesatto et al., 2020; Lechowska, 2018; Schneiderbauer et al., 2021).

Responses to CS are especially important to understand in the context of droughts and water shortages due to the prolonged nature of droughts, which gives sufficient time to respond to weather information and allows for adaptation even during the event (Watts et al., 2012). Human activities, next to climate variability, affect various hydrological processes and in turn, the propagation of droughts (Van Loon et al., 2016; Blair and Buytaert, 2016; IPCC, 2021). CS affect how CS users respond to drought situations, and in doing so, could affect drought hazard, vulnerability, and impacts. These could be beneficial, but they could also lead to counter-intuitive and even counter-productive consequences that result from unexpected behavioural responses (Di Baldassarre et al., 2019).

Synthesising literature on CS user responses and impacts in a drought context would improve understanding of how CS are used, and subsequently how to improve the design of CS for developing suitable adaptation and mitigation strategies. Hence, this paper aims to systematically search for, appraise, and synthesise findings on responses to CS. In particular, we will address the question:

How do CS affect CS users' behavioural, perception and attitude responses in the context of drought?

Our paper contributes to the existing literature by systematically considering responses to CS explicitly, including all CS users, CS types and geographic regions. Moreover, we assess perception and attitude responses to CS.

Theoretical framework

In our systematic review, we use a conceptual framework to analyse how users respond to CS, depicted in Fig. 1. This framework expands that of World Meteorological Organization (2015) and Tall et al. (2018) with insights from Schlüter et al. (2017), who developed a general framework for individual behaviour in socio-economic systems. The framework of Schlüter et al. (2017) is generalisable and hence easily adaptable to the context of CS. Our framework puts emphasis on the role that CS play in informing perceptions, attitudes and behaviour. Articles included our review reported at least one of the paths shown in Fig. 1; either the solid black arrows to include all components, or the dotted arrows to report only behavioural responses to CS (pink), or only responses to CS with attitude or perception (blue). We recognise that not only CS, but also other factors affect responses, for example, policy, education or availability of credit. Studies in which CS, as a factor amongst others, affect responses have been included in this review.

We use the definition of CS from the European Commission (2015):

'The transformation of climate-related data together with other relevant information into customised products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counselling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for the society at large. As such, these services include data, information and knowledge that support adaptation, mitigation and disaster risk management' (European Commission, 2015). Although there is not one singular accepted definition, this definition was selected as it is an inclusive definition, and is widely used (Brasseur and Gallardo, 2016; Bessembinder et al., 2019).

In this literature review, we consider only cases where there is CS uptake in the sense that CS result in documented responses (changes in perceptions, attitudes or observable behaviour). We do not consider papers focused on the mere use of CS, if they do not specify how they have been used. Our focus on responses requires that the CS users are at least aware of and have access to the CS, and that individuals, at least, perceive the existence and availability of CS. To reflect this, in Fig. 1 the box *CS Uptake* is grey to serve as reminder that CS uptake is a requirement to assess attitudes, perceptions and behaviour. It is important to note that this does not mean that CS are trusted or actively used.

After CS uptake, CS affect perception and attitudes of the user, which is included explicitly in our framework. Perception refers to how an individual sees or senses their surroundings. Once information has been perceived, it can alter attitudes. Attitude is a complex construct of which the definition, as well as its methods for quantification and analysis, vary across studies. In this literature review, we define attitudes,

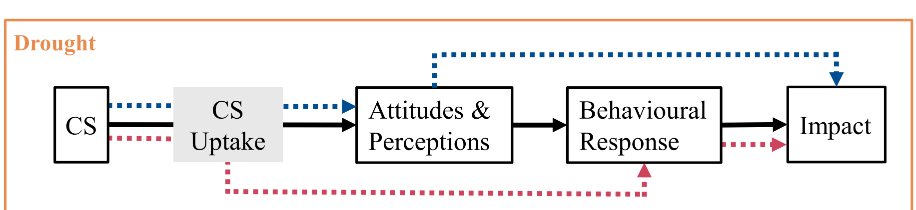


Fig. 1. Framework used in this literature review. Elements depicted by a white box are identified in this review, the element *CS Uptake* (grey box) demonstrates the required CS uptake in the form of awareness and accessibility of CS, the solid black arrow indicates sequence of components. The dotted blue and pink arrows indicate alternative sequences of components without all elements. The orange text and box indicates the hazard in focus, being drought.

according to the Attitudes-Behaviour-Cognition (ABC) model, as how an individual feels about or towards a subject. It is a relatively enduring system of beliefs, feelings, and behavioural tendencies towards an object (Hoggett, 2015). CS may only alter someone's attitudes, for instance to adapting to climate change, but not necessarily lead to an observed behavioural response, e.g. implementation of adaption measures. CS could improve decision-making confidence, even if the same decision/ behaviour results (Tall et al., 2018). Changes in perception and/or attitudes, following from observing CS, may result in an actionable observed behavioural response. A behavioural response refers to 'behaviour that an individual executes as a result from the decision process' (Schlüter et al., 2017).

This does not exclude the option that after perceiving a CS and other relevant decision-making information and the internal decision-making process, deliberately no action is undertaken. Likewise, an individual could respond to CS with behaviour which does not succeed in eventual implementation. It is also possible that a CS user makes a deliberate decision to act against CS advice provided. Hence it is possible that there are unintended CS responses. In the review, we make a distinction between hypothetical and observed behaviour, as well as responses from a game setting, to reflect the diversity of methods used for assessing responses. An observed response indicates the authors considered a realised response to CS. A hypothetical response, in contrast to observed response, is when authors identify what CS users would do or could do with the CS. A game setting response is a realised response to CS in a hypothetical setting e.g. experiments.

Finally, we examine the impacts of CS users' (behavioural and/or attitude/ perception) responses. Here we recognise that an individual's response to CS has an impact on themselves (internal impact), other individuals and their surroundings (external impact). Some of these impacts create feedbacks as the impacts could consequently affect CS design, or continue to change decision making. For example, improvements in irrigation efficiency could lead to increases in water use (Di Baldassarre et al., 2019). By synthesising identified impacts of CS responses, we can connect to existing value of CS literature.

Methods

To ensure transparency and replicability, our literature review methodology is guided by the PRISMA literature review reporting standards (Siddaway et al., 2019). The article selection process is illustrated using the PRISMA flow diagram in Fig. 2. We searched for articles in the Web of Science (WoS) database on 17th November 2022 based on title, abstract, author keywords, and *Keywords Plus*[1]. Table 1 shows that the search string mentioned CS (top rows) and behaviour (middle rows) and droughts (bottom rows) and various synonyms for each. Terms used to capture CS and behaviour keywords have considerable overlap with those identified by Larosa and Mysiak (2019) in their bibliometric analysis of the global CS landscape[2]. We only included English language articles in our search. The search query also excluded proceeding papers, editorial material and book chapters. Lastly, duplicate articles (3) were removed in the identification stage.

During the screening of abstracts (2053 articles), articles were excluded if they did not have empirical findings or did not consider a response to CS. This led to the exclusion of 1931 articles. The remaining 120 articles were found and assessed for eligibility. These articles were read in their entirety, and 32 articles were excluded as they contained duplicate findings, did not consider an empirical response, did not consider a response to CS, or only considered CS uptake (see the Supplementary material for further details). After the screening process, 88 articles were selected (see Table A.2 in Appendix A for list).

From the 88 selected articles, we extracted background information (type of CS users, study area, data collection date and method, data level, sample size, analysis type, and whether droughts were the main focus). To address our main research question, we extracted information pertaining to the CS (form, spatial scale, temporal scale, information conveyed, type of provider, and kind of dissemination) and CS responses (whether the CS response is hypothetical or observed, whether the response is behavioural or perception and/or attitudinal, type of decisions, the impact of the response to the acting individual). Finally, we extracted whether there was any impact due to these CS responses to other individuals and to the surroundings.

Results

Sample descriptive statistics

The 88 selected papers were published between 1999 and 2022, and most studies were conducted in the United States (32%) and Ethiopia (15%) (see Fig. 3). From these papers, 39% had drought as the only considered hazard, 55% considered multiple hazards together including droughts, 7% considered drought explicitly amongst other hazards (see Table B.3).

The sampled papers used various data collection methods (see Fig. 4). Survey or questionnaires and interviews were the most frequently used data collection method, primarily analysed quantitatively. Interviews were equally analysed using a qualitative and quantitative lenses, or a mixed approach. Most articles used or collected data at household and individual level across varying analysis methods (see supplementary materials).

CS characteristics

Figs. 5 illustrate the variety and frequency of CS users and characteristics of the CS they are using. In particular, Fig. 5a shows that farmers make up the majority of CS users in our sample (49%), followed by government officials (15%) and water managers (11%). The form of CS that users receive, with a distinction made according to the temporal scale of the CS, are reported in Fig. 5b. The most prevalent form of CS provided to users is the forecast (44%), followed by early warnings (17%). In general, short term (33%) or seasonal CS (32%) are most commonly reported on. The most common temporal scale within forecasts is seasonal (49%), while for early warnings this is more short term (30%).

Behavioural responses to CS

The type of behavioural responses to CS differ widely between farmers and non-farmers; Fig. 6 illustrates the behavioural responses to CS of farmers (Fig. 6a), and that of non-farmers (Fig. 6b). Farmers predominantly behaviourally respond to CS by changing crops (14%) or changing crop planting/harvesting dates (13%), while non-farmers by changing reservoir management (14%), enacting a plan, policy or programme (13%) or developing a plan, policy or programme (12%). The most common reported information provision to cause a behavioural response are physical indicators for farmers (33%) and non-farmers (34%). Behavioural responses due to the provision of forecast performance information is only reported for non-farmers. Water supply indicators are also more often reported in the context of non-farmers (20%) compared to farmers (10%). This also holds for social indicators; non-farmers respond to social indicators in 14% of reported articles, which is higher compared to farmers (6%).

This difference between farmers and non-farmers is also reflected in the form of CS that users are responding to. Fig. 7 shows that farmer

[1] *Keywords Plus* are index terms automatically generated from the titles of cited articles. According to Zhang et al. (2015) *Keywords Plus* terms are less specific descriptors of the content of articles, compared to author keywords, and therefore beneficial to include in search.

[2] Larosa and Mysiak (2019) show that the most frequently identified keywords include 'climate change', 'decision making' and 'forecasting'.

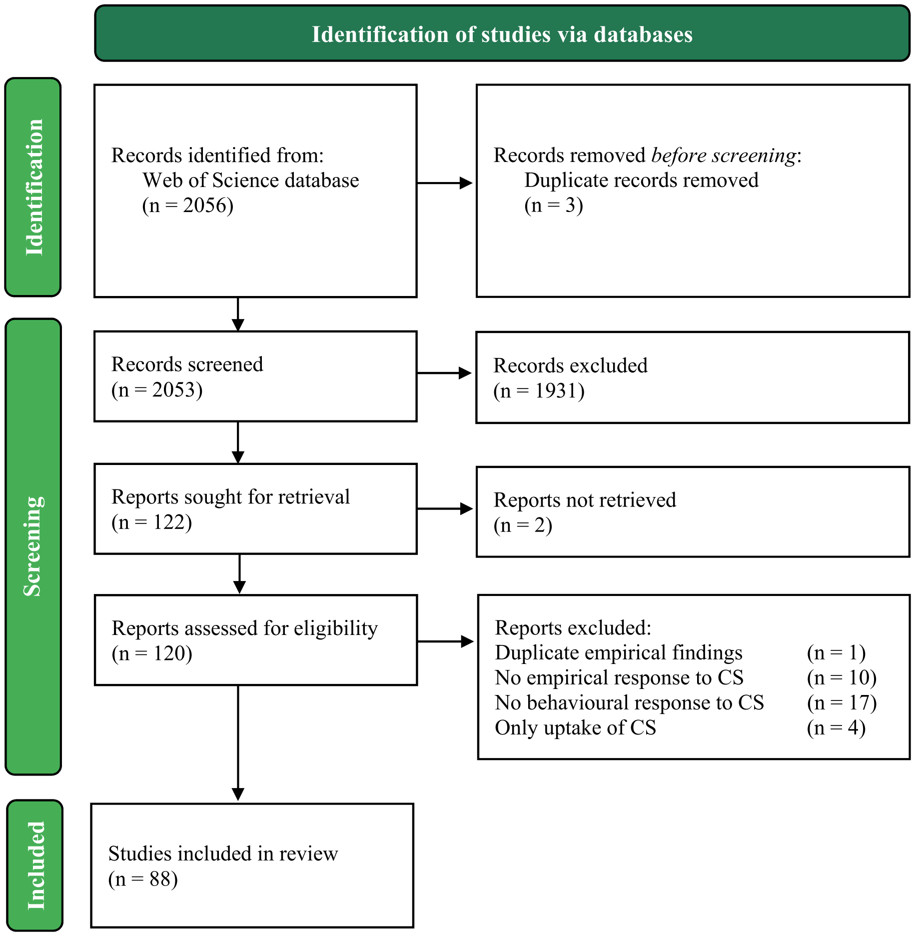


Fig. 2. Article identification and screening process based on the PRISMA flow diagram for systematic reviews. *Note: n refers to number of articles.*

Table 1
Search terms used to search through article title, abstract, author keywords, Keywords Plus. *Note: The dollar sign ($) represents zero or one character. The asterisk (*) represents any group of characters, including no character. The hyphen (-) represents a space or hyphen character. Quotation marks (" ") indicate that an exact phrase is searched.*

"climate service$"	OR	"climate information"	OR	"climate knowledge"	OR
"weather-information"	OR	"climate product$"	OR	"forecast$"	OR
"early-warning$"	OR	"monitoring-system"	OR	"decision-support-system"	
			AND		
mitigat*	OR	adapt*	OR	behavio$r*	OR
"risk-perception"	OR	"risk-awareness"	OR	"decision-making"	OR
uptake	OR	preparedness	OR	"risk-management"	OR
"early-action"	OR	choice	OR	awareness	OR
"risk-preference$"	OR	"risk-attitude$"			
			AND		
drought$	OR	"drought-risk$"	OR	"water-shortage$"	OR
"water-resource$"	OR	"water-securit*"	OR	"water-stress"	

(46%) and non-farmer (46%) behavioural responses have mainly been informed by CS in the form of forecasts. In the case of farmers, fertiliser (60%) and marketing (46%) management are most informed by forecasts. Responses with changing crop types or variety, or crop planting or harvesting dates, are each informed by forecasts in 55% of cases. For non-farmers, livelihood diversification (100%), labour allocation (67%), reservoir management (56%) and information search or diffusion (56%) changes are mostly informed by forecasts. Articles more often report CS in the form of training or education for non-farmers (14%) compared to farmers (7%). Only one paper assessed the responses to indigenous knowledge indicators by farmers, namely, Ankrah et al. (2022) explore responses to indigenous knowledge indicators alongside science-based predictors. Decision support tools have also only been discussed within a farming context (Nyerges et al., 2006; Soto-Garcia et al., 2013). On the other hand, indexes have only been reported in the case of non-farmer behavioural responses (Steinemann, 2006; Guido et al., 2013). In general, the form of CS is more often unspecified by articles studying CS responses by farmers (13%), compared to non-farmers (2%).

Perception and attitude responses to CS

There are fewer reported responses by perception and attitude (12%) compared to behavioural responses (88%) to CS (for further details, see the supplementary materials). Studies that report responses to CS with attitudes and perceptions find mostly changes in perceived climate indicators and self-reported improved understanding. Fig. 8a shows that farmers respond most frequently by a changed perception of temperature (22%) and droughts (17%). The perception and attitude responses to CS of users other than farmers in Fig. 8b are mostly self-reported improved understanding (48%) of their situation. The information that the CS provide to farmers is more frequently not specified (67%) compared to CS non-farmers (19%). The information that the CS provides to farmers is also less diverse (colours in Fig. 8).

The form of CS that instigated responses with attitudes and perception changes were relatively equally spread. Due to the limited number of studies reporting responses with attitude and perception changes, this has been reported in the supplementary materials. For farmers, changes

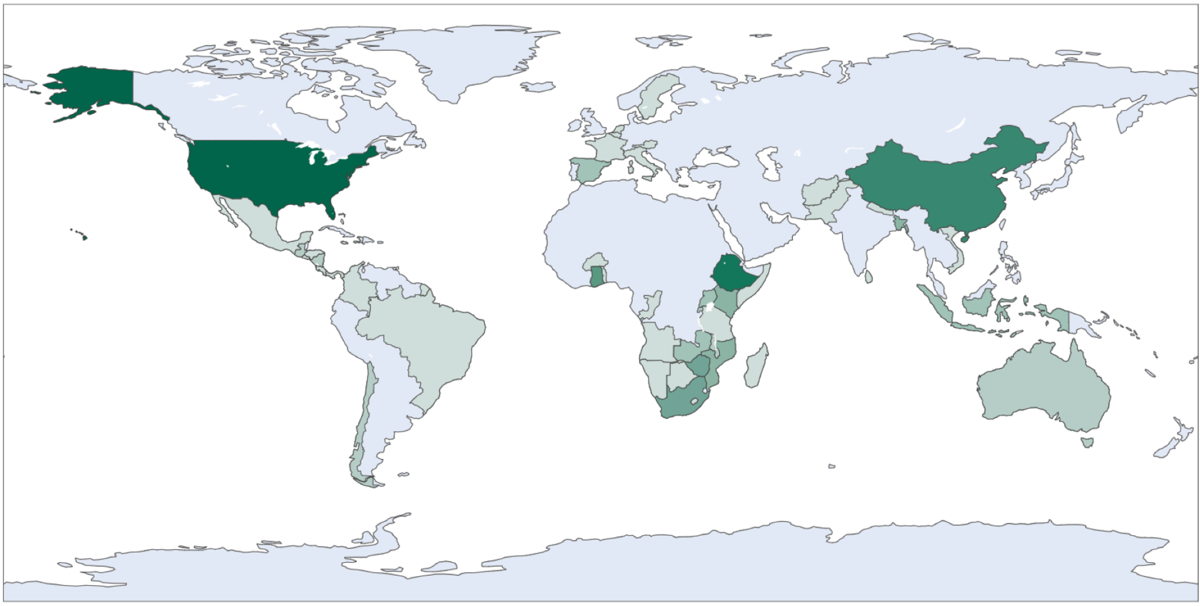


Fig. 3. Location of empirical data collection in article sample. *Note: six papers collect empirical findings at multiple locations, hence the sum of the frequencies (n = 123) is larger than the number of papers.*

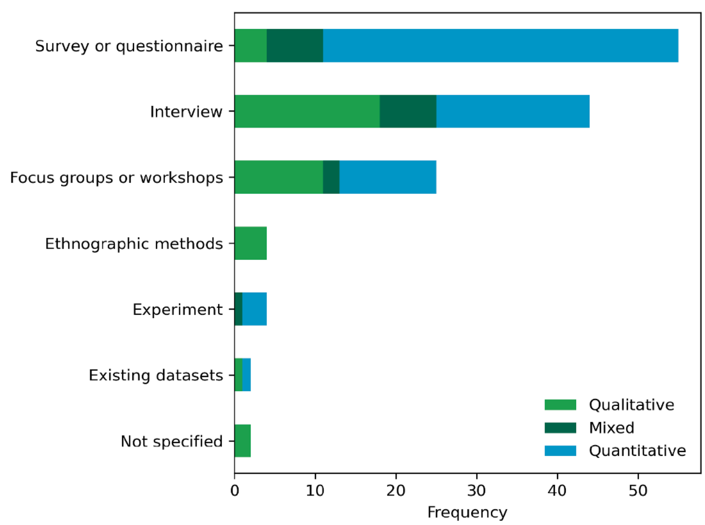


Fig. 4. Data collection method according to analysis type. *Note: thirty-three papers make use of multiple data collection methods, hence the sum of the frequencies (n = 136) is larger than the number of papers.*

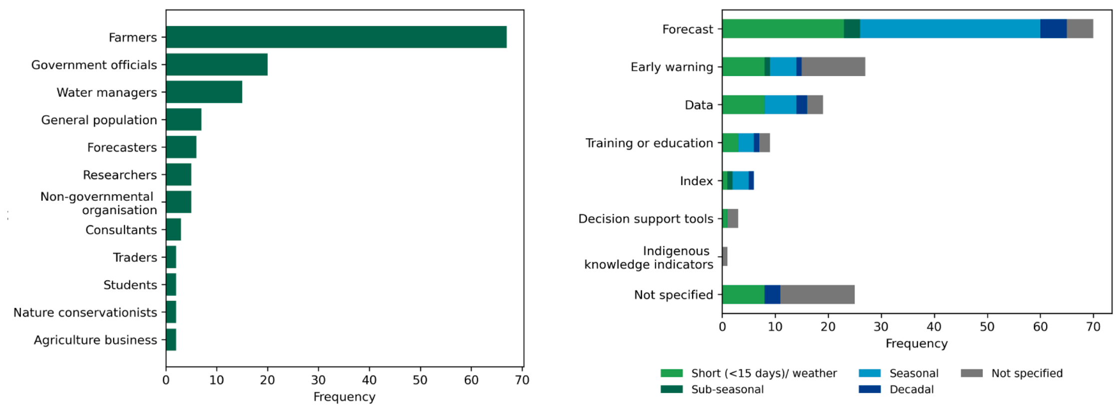
in confidence in decision making and perceived adaptation options are informed by data, early warnings, forecasts and training or education. In the case of non-farmers, improvements of understanding are responses to data, decision support tools, early warnings, forecasts, indexes.

Responses to CS and their impacts

Responses to CS can have an effect on the users themselves, but also their surroundings. In our sample, 24 papers identified impacts that CS users experience as well as the impacts experienced by their surroundings. These 24 papers showed 37 types of CS users, predominantly farmers (59%), who reported positive (71%), mixed (13%), negative (17%) impacts due to their CS responses. Mostly, farmer impacts were calculated in terms of costs (e.g. reduced irrigation frequency and hence costs) or in terms of revenue, while for non-farmers the impacts identified are more diverse.

Positive impacts to the CS users themselves primarily consist of retained/increased crop or livestock revenues (Buckland and Campbell, 2022; Ewbank et al., 2019; Ngango and Hong, 2021; Song et al., 2018; Wang et al., 2019; Gunda et al., 2017; Patt et al., 2005; Haigh et al., 2019). Other positive impacts of using CS include improved quality of life (Soto-Garcia et al., 2013; Changnon, 2002), livelihood diversification (Ndlovu et al., 2020), improved food security (Staub and Clarkson, 2021), better use of water (Crochemore et al., 2021).

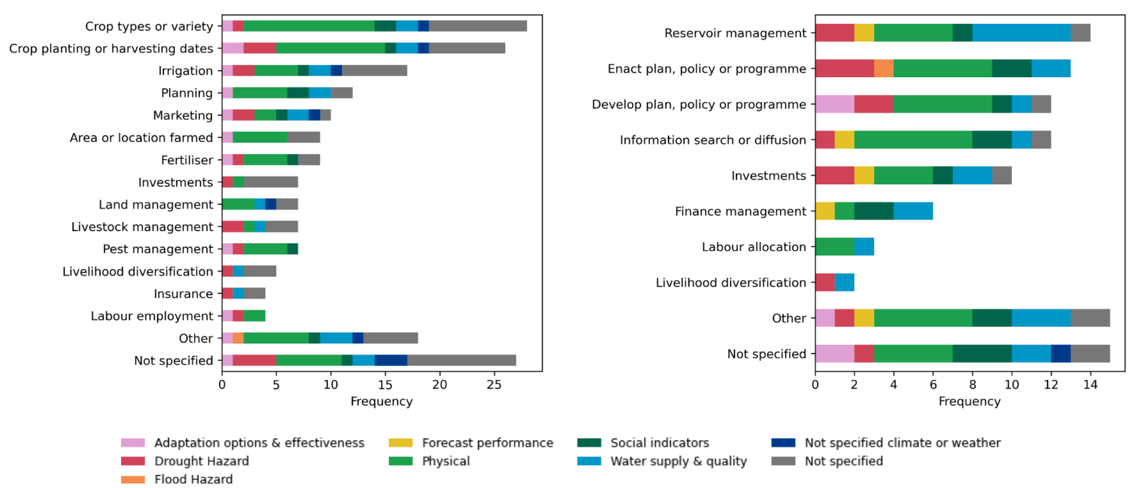
Few CS were reported as ineffective or resulted in adverse internal impacts to CS users. One such case is highlighted by Changnon (2002) when long-range forecasts predicted a worsening drought and were widely publicised without stating forecast skill or uncertainty. This influenced farmers to adjust their strategies (e.g. reduce crop production, postpone sales of their old crops and not forward pricing their new



(a) Types of CS users ($n = 136$).

(b) Form and temporal scale of the CS ($n = 160$).

Fig. 5. CS users and characteristics of the CS they are using. *Note: Several papers record multiple CS users and CS, hence the sum of the frequencies ('n' listed in sub-figure caption) is larger than the number of papers.*



(a) Farmer behavioural responses to CS ($n = 197$).

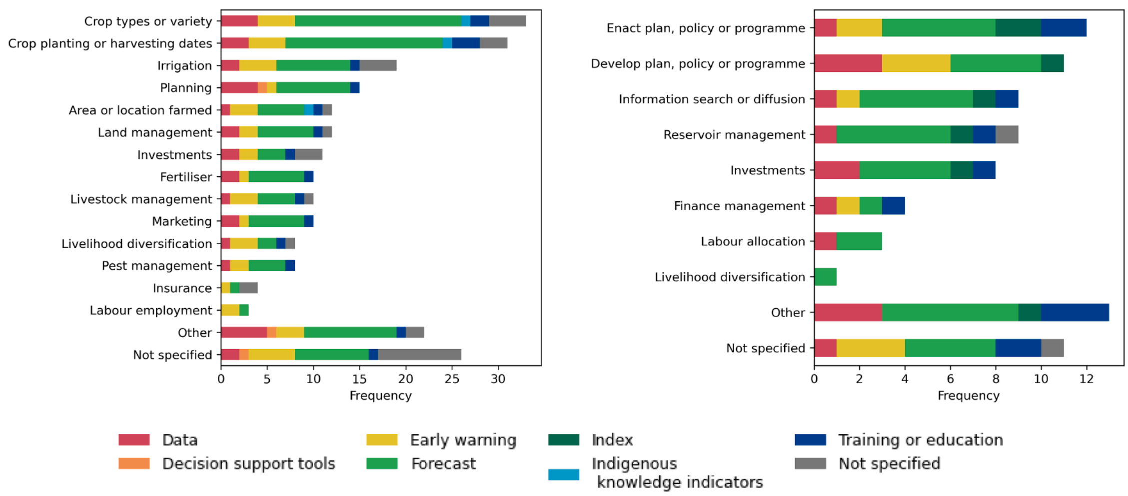
(b) Non-farmer behavioural responses to CS ($n = 102$).

Fig. 6. Behavioural responses to CS, according to CS user type and information provided with CS. *Note: for clarity, the frequency scales of the bar-charts are not the same. Several papers record multiple responses and/or provide various types of information, hence the sum of the frequencies ('n' listed in sub-figure caption) is larger than the number of papers.* For further information on category contents, see Appendix B.

crops). This warning was a false positive, and consequently farmers had lower crop sale revenues (Changnon, 2002). The form of the CS also has an effect; Demnitz and Joslyn (2020) identified that deterministic CS (forecasts) used in crop choice tasks resulted in higher risk aversion than was appropriate, resulting in lower profits for diverse CS users, compared to probabilistic forecasts. Crochemore et al. (2021) find that seasonal forecasts which were not reliable or sharp also increased risk aversion, however, unlike Demnitz and Joslyn (2020), risk averse decision-making was not associated with solely negative outcomes. Crochemore et al. (2021) conducted a serious game about reservoir management where participants received seasonal forecasts with varying sharpness and reliability[3] to consequently decide to wait and see, do nothing, sell water surplus or contact neighbouring water authorities for advice. The overall most optimal strategy was to purchase better forecasts and take calculated risks. In the sub-optimal case the participant chose not to purchase better forecasts, a risk averse strategy (e.g. not selling surplus water) was optimal. Lastly, CS content has been identified to have internal impact. Siregar and Crane (2011) reported that farmers ignored the CS as they felt it provided misguided and inappropriate farming advice; the CS aimed to improve understanding of various forecasts, which in this case indicated an oncoming dry season, implying that farmers should switch to less water intensive crops. Farmers ignored the CS as it did not consider interrelated social, technical, and ecological conditions[4]. Despite the consequent dry period, by ignoring the CS, farmers were not negatively impacted compared to if

[3] Here reliability represents how often the observation has fallen within the forecast range in the past, as a percentage. Sharpness conveys the degree of uncertainty in the forecasts (Crochemore et al., 2021).

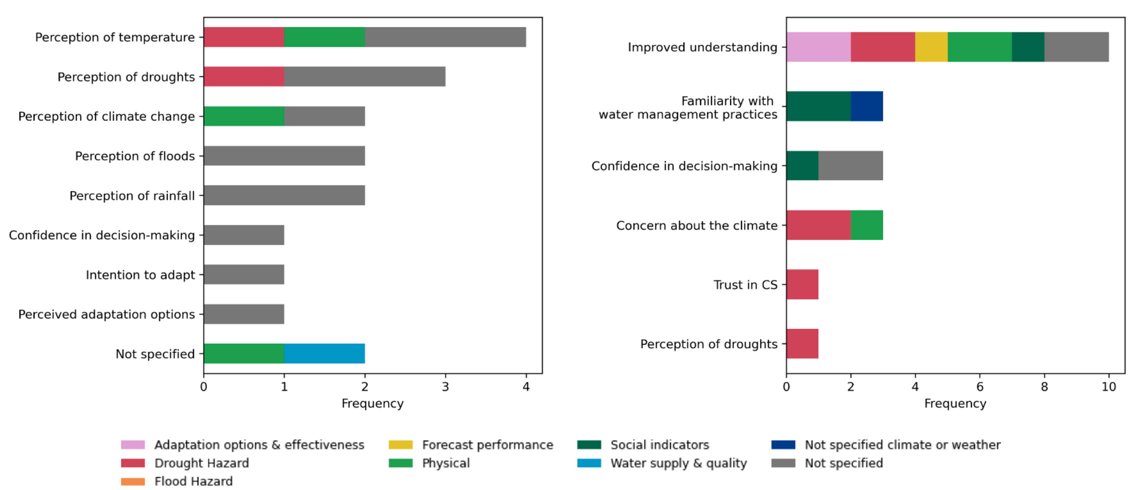
[4] Farmers had more technical knowledge when it came to growing rice, as well as rice requiring less time and effort to cultivate than other crops. Farmers also made use of a shared irrigation system, meaning adaptive decision-making at the individual level is not viable. Pests were managed by planting or harvesting rice at the same time as other farmers; pressures from rat predation would be evenly distributed amongst all synchronised farmers (Siregar and Crane, 2011).



(a) Farmer behavioural responses to CS ($n = 234$).

(b) Non-farmer behavioural responses to CS ($n = 81$).

Fig. 7. Behavioural responses to CS, according to user type and CS format. *Note: for clarity, the frequency scales of the bar-charts are not the same. Several papers record multiple responses and/or provide various forms of CS, hence the sum of the frequencies ('n' listed in sub-figure caption) is larger than the number of papers.* For further information on category contents, see Appendix B.



(a) Farmer attitude and perception responses to CS ($n = 21$).

(b) Non-farmer attitude and perception responses to CS ($n = 29$).

Fig. 8. Responses to CS with perception and attitudes, according to user type and information provided with CS. *Note: for clarity, the frequency scales of the bar-charts are not the same. Several papers record multiple responses and/or provide various types of information, hence the sum of the frequencies ('n' listed in sub-figure caption) is larger than the number of papers.* For further information on category contents, see Appendix B.

they had followed the CS recommendation.

External impacts of CS user responses are mixed. Ellison et al. (2019) reported that farmer CS users facilitated community decision-making about water resources, e.g., voluntary releases of privately held licensed water. This not only had a positive impact on the community, but also on the surrounding environment. Vedwan et al. (2008) found that the provision of lake discharge CS to water managers also not only improved lake management, but also indirectly lead to a reduction of exotic vegetation species. On the other hand, CS have also contributed to increased illegal water abstraction, which resulted in downstream river water shortages that heavily impacted downstream water users (Sifundza et al., 2019). CS could enhance food shortages, as a study by Phillips et al. (2002) analysed. They observed that when drought was forecast, Zimbabwean farmers responded by reducing area planted. They thereafter modelled what would have happened if CS were introduced in Zimbabwe earlier and found that the introduction of CS would have led to more volatile food supply. When drought would be forecast, fewer crops would be planted, and severe food shortages occur, while when no drought was forecast food supply would be greater than historically observed levels (Phillips et al., 2002).

CS user responses can have positive external impacts, according to two studies focusing on social networks. Farmers receiving CS, and as a result adjusting planting dates and crop types, led to improved yields in some cases. This caused other farmers, who were not making use of CS, to want to use CS (Patt et al., 2005). A study in Zimbabwe found that CS also influenced CS users to adopt climate-smart practices (e.g.

conservation farming, rainwater harvesting techniques and solar energy usage), which encouraged livelihood diversification (e.g. bee keeping) not only of the CS user themselves, but also of others in the community not using CS (Ndlovu et al., 2020).

Discussion

Our review set out to synthesise the existing evidence of how CS influence attitudes and perceptions, and observable behaviour. This evidence was found to be scattered, and often limited in scope.

Studies reporting empirical responses to CS mainly focused in the United States, Ethiopia and China, however, this may not be where drought risk is greatest. Carrão et al. (2016) and Oh et al. (2023) calculate highest drought risk in India, Nigeria and Eastern Europe, however, none are represented in our sample. Meza et al. (2020) focused on drought risk for agricultural systems and had Zimbabwe, Namibia and Botswana ranked as highest drought risk countries. In our sample of empirical studies, Zimbabwe is the best represented (6 articles), while Namibia and Botswana are studied in 1 article respectively.

The predominant form of CS being forecasts, early warnings and data could indicate that CS still focus on delivering better data, compared to a focus on better decision-making (Findlater et al., 2021). Few CS included a training or education element to increase understanding of climate information, or integrated local knowledge indicators to study responses.

The large proportion of studies that focus on farmers as CS users could reflect either more provision of CS to farmers or more reporting on CS use of farmers. This research focus may be related to the fact that farmers experience direct impacts of drought, and their connection to food security (Anwar et al., 2013). Cortekar et al. (2020) found that mainly public decision makers/politicians, researchers and the general public/media are targeted as CS users, and the main targeted sectors of CS include water, energy (incl. renewables), agriculture and urban/spatial planning. The sectors identified by Cortekar et al. (2020) align with our identified CS users, however, the targeted CS users do not. This could be due to our global review scope or our focus on droughts and water scarcity.

Our findings of farmer behavioural responses align with those discussed by Tall et al. (2018),Nkiaka et al. (2019) and Suckall and Soares (2022), and with findings of adaptation strategies to climate change in general. Harmer and Rahman (2014) reviewed papers published between 2009 and 2014 on adaptation strategies to climate change in developing countries and found that crop changes, changing of planting or harvesting dates, adjustments of irrigation, and land management are most frequently reported, whereas financial and labour employment are the least often reported adaptation strategies. The types of adaptation strategies discussed by Anwar et al. (2013) interestingly align with findings presented in this paper, although they do not consider it a prerequisite that farmers have responded to CS. This could indicate that CS do not broaden the scope or type of responses to climatic challenges.

Given that attitudes and perceptions act as a mediator between CS and responses to CS, it is surprising that they have not been frequently reported in our sample; and this remains an important topic for further research. One reason for this could be our explicit focus on droughts and water scarcity. It is plausible that literature exploring perceptions and attitude changes due to CS is not focused on specific hazards. For example, the review by Ripberger et al. (2022) highlights studies addressing the impact of forecast probability communication on decision making, however, much of the cited work does not specify the specific targeted hazard. In our review, we found learning effects are present when false positive warnings are given, however, how CS and CS characteristics directly affect trust has not been identified.

The type and number of attitudinal and perception changes in the studies is also somewhat limited compared to studies on the use of technologies other than CS. For example, Bartkowski and Bartke (2018) show that entrepreneurial and environmental attitudes, trust, as well as social norms influence farmers' decision-making. In this review, how CS and CS characteristics directly affect such attitudes has not been identified. CS development would benefit from an improved understanding of the attitudes and perceptions, and how these, together with the behavioural responses, vary between users, so that CS can be better tailored to individual users or user groups.

We identified that only 27% of articles report the impact of CS, which confirms the findings of Tall et al. (2018). We agree that this could be due to difficulties attributing impacts to CS; tracking information flows and isolating impacts of complex social and economic systems can make causal inferences challenging. This difficulty in identification of impacts could also motivate the lack of variety of impacts reported. Economic gains/losses (for instance, crop losses converted into monetary losses) are most often reported, while environmental impacts are least identified, aligning with the findings of Suckall and Soares (2022). It could also be questioned whether the predominantly positive impacts of CS reported truly reflect the impact of CS. The positive impacts could be attributed to the growing quality of climate information, growing involvement of stakeholders, however, it could also reflect positive publication bias due to the small number of impacts reported.

Due to challenges in attributing impacts to CS, much of the CS impact literature relies on ex-ante quantitative modelling, which make strong assumptions; CS users and providers are homogeneous, have perfect knowledge, perfect forecasts, limited response options (Tall et al., 2018; Soares et al., 2018; Clements et al., 2013). Findings of our review may help to adjust such models towards empirically observed responses.

Internal and external impacts can cause CS users to learn and change their responses in the future, however, this has been minimally reported. Learning feedback processes were reported in only 3% of our sample. Changnon (2002) and Dilley (2000) found that because of a false early warning, which the CS users trusted and responded to, they were negatively impacted. They learned from this experience, and claimed that in the future they will trust the early warnings less or will not use them at all. Crochemore et al. (2021) showed that participants grew more risk averse if, using the provided forecasts, they did not anticipate an excess or shortage of water supply. After this experience, participants indicated to consider forecast uncertainty more seriously. Understanding such dynamic processes could help to improve CS and their use and perhaps overcome maladaptation caused by CS. To date, however, there is too little information provided in the papers about the immediate impacts, let alone the dynamic impacts, to identify responses as being either intended (from an adaptation planner perspective) or maladaptive.

Our results are reliant on the quality of our search terms and screening process. Although we used a comprehensive set of keywords, it is plausible that some papers were omitted due to our keywords specification. We also only included papers in English, which may have led to the exclusion of relevant papers published in other languages. To minimise the bias during the screening process, the first author conducted the identification and screening process, with questionable cases resolved with remaining listed authors. This is also the case for data collection from articles.

Conclusion

In this systematic literature review, we provide an overview of empirically identified CS users' behavioural, perception and attitude responses to CS, in the context of droughts. To our knowledge, this is the first review including responses in perceptions and attitudes to CS. This literature review also broadens the scope and depth of understanding responses to CS compared to existing reviews, by including all types of CS, CS users and geographical regions.

Out of the 88 selected papers, the majority of articles discuss CS users and CS responses, related to agriculture. In particular, CS predominantly influence farmers to change planting or harvesting dates, and crop type. In terms of attitude and perception responses, farmers mostly change their perception of droughts, temperature and climate change. There are fewer papers reporting on changes in perceptions and attitudes as a result of CS for all users. Other CS users studied in the reviewed papers are water managers and government officials. Their behavioural responses consist mainly of developing plans and enacting them, while perception and attitude responses mainly consist of changed familiarity with water management practices. As a result of these responses to CS, mainly positive impacts for the CS user themselves, but also for others and the environment have been reported. Users have also learned from their responses to CS; for example, having acted upon a false positive forecasts can be costly, and cause future distrust in warnings.

We argue that our overview provides an evidence base towards the assessment of impacts of CS. It also helps to inform the currently restrictive ex ante quantitative assessments and modelling exercises that aim to assess how climate services and information can help socio–hydrological systems to adapt to droughts and other climate hazards. Tailoring CS to the needs, experience, knowledge, attitudes and decision-making spaces of users could help users to make better-informed choices. This is likely to require a shift from providing precise data on climate and weather towards providing training on how to use this data, based on understanding how such data changes perception, behaviour, actions and impacts of users. This should include potential drawbacks of using the data, given their uncertainties. Additionally, due to the long-lasting nature of drought, we recommend further research into the dynamic use of CS, as this can in some sectors promote no-regret measures and continuous adaptation, and prevent maladaptation.

Declaration of Competing Interest

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

Data availability

The literature review database pertaining to sample articles and their classifications is openly available via: https://zenodo.org/record/8215154 (Muller et al., 2024).

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Appendix A. Additional selection information

Table A.2
List of the 88 included papers.

Accepted articles					
Alauddin and Sarker (2014)	Alauddin et al. (2020)	Ali et al. (2020)	Ankrah et al. (2022)	Asfaw et al. (2019)	Bouroncle et al. (2019)
Brondizio and Moran (2008)	Buckland and Campbell (2022)	Carr et al. (2018)	Carson et al. (2018)	Changnon (2002)	Chen et al. (2014)
Cobon et al. (2021)	Coles and Scott (2009)	Crane et al. (2011)	Crochemore et al. (2021)	de Klerk et al. (2021)	de la Poterie et al. (2018)
Debela et al. (2015)	Demnitz and Joslyn (2020)	Dilley (2000)	Donatti et al. (2017)	Eakin and Conley (2002)	Ekstrom et al. (2017)
Ellison et al. (2019)	Emerton et al. (2020)	Etana et al. (2020)	Ewbank et al. (2019)	Fagariba et al. (2018a)	Fagariba et al. (2018b)
Gebeyehu et al. (2021)	Grey (2019)	Guido et al. (2013)	Gunda et al. (2017)	Haigh et al. (2019)	Ho et al. (2022)
Hou et al. (2017)	Huang et al. (2020)	Kam et al. (2019)	Kansiime (2012)	Kawanishi et al. (2016)	Khan et al. (2021)
Khanal and Wilson (2019)	Klopper (1999)	Kom et al. (2022)	Kumar et al. (2020)	Kuswanto et al. (2019)	Li et al. (2017)
Lines et al. (2018)	Maggio and Sitko (2019)	Marie et al. (2020)	McConnachie and Cowling (2013)	Messmer et al. (2021)	Ndamani and Watanabe (2016)
Ndiritu (2021)	Ndlovu et al. (2020)	Ngaka (2012)	Ngango and Hong (2021)	Nkuba et al. (2022)	Nyamekye et al. (2021)
Nyerges et al. (2006)	Owusu and Yiridomoh (2021)	Partey et al. (2020)	Patt et al. (2005)	Paul and Routray (2011)	Phillips et al. (2002)
Roco et al. (2014)	Roco et al. (2016)	Salite (2019)	Sertse et al. (2021)	Sharif et al. (2019)	Sifundza et al. (2019)
Siregar and Crane (2011)	Song et al. (2018)	Soto-Garcia et al. (2013)	Staub and Clarkson (2021)	Steinemann (2006)	Teague et al. (2021)
Vedwan et al. (2008)	Wang et al. (2019)	Wang et al. (2015)	Wens et al. (2021)	Werner et al. (2013)	West et al. (2014)
Wiener et al. (2020)	Zamasiya et al. (2017)	Ziolkowska (2018)	Ziolkowska et al. (2017)		

Appendix B. Classification clarification

In this section, we elaborate on the contents of the created groups to describe CS characteristics, behavioural, perception and attitude responses to CS.

Table B.3
Descriptions of category contents used to report CS characteristics, behavioural, perception and attitude responses to CS.

Category	Term	Description
CS characteristics: Types of information provided	Adaptation options and effectiveness	Information about adaptation options and their effectiveness, for example, crop, seed or fertiliser information and the hypothesised impact of adaptation choices. This category also includes communication of safety best practices during hazards.
	Drought hazard	Composite indicators of drought likelihood, occurrence, intensity or duration.
	Flood hazard	Composite indicators of flood risks and debris flows.
	Forecast performance	An indicator of forecast performance.
	Physical	Information about direct or raw environmental indicators, for instance rainfall, temperature, wind speed. It is unspecified for which hazard this raw information is tailored to.
	Social indicators	This includes various social indicators for instance, price, demographic, vulnerability information.
	Water supply & quality	Information about direct or raw environmental indicators of water supply and quality, for example, reservoir volume, water level, river discharge.
	Not specified climate or weather	This category accounts for studies who have not stated the type of information provided besides 'weather information' or 'climate information'.
CS characteristics: form	Data	The provision of (improved) raw data about either current, or historical records. Unspecified time span of records is also included in this category.
	Decision support tools	The provision of a tool which analyses data in support of decision making.
	Early warning	The provision of a warning regarding one or more hazards.
	Forecast	The provision of a prediction or estimate of future trends or events.
	Index	Provision of a composite indicator relative measure of the weather or climate conditions.
	Indigenous knowledge indicators	In classifying we followed the specification of Mistry (2009), namely 'knowledge which is spatially and/or culturally context specific, collective, holistic, and adaptive'. This could include using climatic (e.g. cloud formation), vegetational (e.g. flowering trees), animal (e.g. croaking frogs) and social behaviours (e.g. rituals) as predictors of weather and/or climate (Bharara and Seeland, 1994).
	Training or education	Provision of training or education.
Behavioural responses (Farmer)	Area or location farmed	Changing the location farmed or changing the size of the area cultivated.
	Crop planting or harvesting dates	Changing the crop calendar e.g. planting, harvesting, fallow period.
	Crop types or variety	Changing the crop types, or the variety of crops planted.
	Fertiliser	Changing type of fertiliser, or fertiliser application time or quantity.
	Insurance	Purchasing insurance, or changing the level of insurance coverage.
	Investments	Change in Investments in infrastructure or technology e.g. irrigation facilities, wells, cisterns. This category also includes changing the timing of investments.
	Irrigation	Changing the frequency, timing or type of irrigation.
	Labour employment	Changes in quantity, quality or timing of labour employment e.g. changing degree of manual labour used.
	Land management	Changes in how the land is prepared e.g. land augmentation, row spacing, tillage or broadcasting of seeds.
	Livelihood diversification	(Partial) shifts in income sources.
	Livestock management	Changes related to how livestock is managed, for example, (timing of) grazing, culling breeding herd, calving dates. It also includes changes in livestock inventory, storing or purchases of hay or feed.
	Marketing	Changes in sale strategies, for example, timing of livestock sales, forward price changes, adjustments of market practices.
	Pest management	Includes changes in timing, type or method of pesticide dispersion.
	Planning	Changes in the timing of decisions, scheduling agricultural activities (e.g. crop rotations), or financial plans.
	Other	Various measures which did not fit in the above categories, for example, reduction of water usage, complaints about water distribution, non-farming related expenditures.
Behavioural responses (Non-farmer)	Develop plan, policy, or programme	Develop a new plan, policy or programme, e.g. disaster relief, drafting proposals, streamline disaster declarations.
	Enact plan, policy, or programme	Enacting a prior developed plan, policy or programme, e.g. invoke, revoke or maintain drought restrictions, livestock assistance grant, emergency responses.
	Finance management	Focus on the management of budgets, raising funding or release or retention of grain stock.
	Information search or diffusion	Seeking further information, or disseminating information e.g. convene drought groups, seek educational programmes, google searches about drought.
	Investments	Change in Investments in infrastructure or technology (drilling boreholes, wells, cisterns etc…). This category also includes changing the timing of investments.

(continued on next page)

Table B.3 (*continued*)

Category	Term	Description
	Labour allocation	Changes in quantity, quality or timing of labour employment e.g. Alter staff activities.
	Livelihood diversification	(Partial) shifts in income sources.
	Reservoir management	Decisions related to the working of reservoirs e.g. (no) sale of surplus water, move water between reservoirs, change CS action trigger values.
	Other	Various measures which did not fit in the above categories, for example, reduction of water usage, cancelled rafting season, illegal water abstraction.
Perception and attitude responses (Farmer)	Confidence in decision-making	Changes in an individual's sense of satisfaction or confidence in their decision.
	Intention to adapt	Changes in an individual's intention to implement an adaptation.
	Perceived adaptation options	Changes in perceived number or effectiveness of adaptation options.
	Perception of climate change, droughts, floods, rainfall, temperature	Changes in perception of prevalence, intensity, occurrence of climate change, droughts, floods, rainfall, temperature.
Perception and attitude responses (Non-farmer)	Concern for the climate	Changes in the degree of concern for the climate.
	Confidence in decision-making	Changes in an individual's sense of satisfaction or confidence in their decision.
	Familiarity with water management practices	Changes in familiarity with water management practices e.g. familiarity with building or enhancing levees.
	Improved understanding	Changes in general understanding of various topics e.g. droughts, data, weather variability.
	Perception of droughts	Changes in perception of prevalence, intensity, occurrence of droughts.
	Trust in CS	Degree of trustworthiness assigned to the CS.

Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.cliser.2024.100493.

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