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# HESS Opinions: Drought impacts as failed prospects

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**Abstract.** Human actions induce and modify droughts. However, scientific gaps remain with respect to how hydrological processes, anthropogenic dynamics, and individuals' perceptions of impacts are intrinsically entangled in drought occurrence and evolution. This adds complexity to drought assessment studies that cannot be addressed by the natural and environmental sciences alone. Furthermore, it poses a challenge with respect to developing ways to evaluate human behaviour and its pattern of co-evolution with the hydrological cycle – mainly related to water use and landscape modifications. During fieldwork in Brazil, we observed how drought impacts were experienced by people who were exposed to a multi-year drought. Evaluating our data, it appeared that prospect theory, a behavioural economic theory that is usually applied to explain decision-making processes under uncertainty, has explanatory power regarding what we observed in the field. Therefore, we propose an interdisciplinary approach to improve the understanding of drought impact emergence using this theory. When employing prospect theory in this context, drought impacts are considered failed welfare expectations ("prospects") due to water shortage. A shifting baseline after prolonged exposure to drought can therefore mitigate experienced drought impacts. We demonstrate that this theory can also contribute to explaining socio-hydrological phenomena, such as reservoir effects. This new approach can help bridge natural science and social science perspectives, resulting in integrated drought management that considers the local context.

## 1 Introduction

During fieldwork conducted by the authors of this paper in the semi-arid region of Brazil (SAB), a farmer was asked how the 2012–2018 multi-year drought event (Cunha et al., 2019b, 2018; Marengo et al., 2020; Cunha et al., 2019a) had affected his livelihood and welfare. The farmer responded by asking "Drought? What drought?". We wondered how a drought event that lasted for almost 7 years and was characterized by an average 60 % reduction in annual precipitation had gone unnoticed by someone who had been in the middle of it. A spatial contextualization helped us answer this question. The farmer's property was located at the edge of an upstream reservoir with low water abstraction that retained water throughout this drought event. Therefore, he never experienced water insecurity during this period.

The farmer's response implicitly reveals the relationships between human actions that modify hydrological processes (in this case, the construction of a reservoir) which alter exposure to a drought hazard (in this case, no exposure because of a filled reservoir) as well as individuals' perceptions of disaster occurrence ("Drought? What drought?"). This is in line with the concept of "Drought in the Anthropocene" (Van Loon et al., 2016), which underlines the need to consider the human component as an inseparable part of the complex and interrelated processes of a drought. It calls for more balance between the analysis of the physical and human component of drought events, where we define drought as an exceptional period of lack of water compared with normal conditions. This is not restricted to a physical cause (e.g. a negative rainfall anomaly) but can also be caused, or mitigated, by human actions. These ideas are developed in the context of socio-hydrology. This field aims to study the dynamics and co-evolution of human–water coupled systems, with one of the main premises being that human actions are an endogenous part of the hydrological cycle (Sivapalan et al., 2012, 2014; Pande and Sivapalan, 2017). In other words, people interact with the hydrological system in various ways (e.g. water consumption and landscape modification), and this has the potential to alter hydrological processes, which in turn influence and impact human actions, creating a co-evolution.

Perceiving the human component as an inseparable part of the hydrological cycle creates new research avenues – for instance, the study of drought events and other disasters at scales that are commonly disregarded, such as starting from the individuals in the hydrological system that experience impacts and evaluating the decisions that they make to avoid these impacts. This may reveal the emergence of patterns and phenomena unobserved at other spatio-temporal scales or when focusing on other hydrological variables (Wens et al., 2021, 2019; Van Oel et al., 2012; Walker et al., 2022). Although the patterns of co-evolution between the human component and the hydrological cycle have been widely debated in the scientific literature (Sivapalan et al., 2012; Di Baldassarre et al., 2015; Van Loon et al., 2016; Di Baldassarre et al., 2019; Tian et al., 2019), gaps remain regarding the relationship between hydrological hazards (e.g. drought), the perception of the impact of this hazard, and the occurrence of the hazard itself. With the ideas presented in this paper, we aim to contribute to this discussion, focusing on drought hazards.

We argue that the collectivity of individuals' perception of the impacts that they experience, which is related to both environmental and socio-economic factors, determines the magnitude and the very occurrence of a drought event. Using prospect theory (Kahneman and Tversky, 1979), which stems from the field of behavioural economics, we can explain the emergence of drought impacts, considering impacts as failures in expected welfare due to water shortages. We build our case by first presenting the concept of drought impacts as failed prospects and then outlining the relationship between socio-hydrology and prospect theory to finally present how this can be applied to real-world cases of drought events.

## 2 Impacts as failed prospects

Satisfying our needs for welfare, and not just survival, is one of the characteristics that define us as humans. An improved understanding of how this influences decision-making related to water use and landscape modification can lead to a better drought assessment. Human beings, as individuals, anticipate a desirable level of welfare and then choose among the possible prospects that they believe have the highest chance of achieving this goal (Kahneman and Tversky, 1979). These prospects are the decision options that are associated with an expected outcome within a scenario of uncertainties.

The chosen prospect defines how well an individual is adapted to their environmental conditions; therefore, it is directly related to their vulnerability and resilience. We propose that, when an individual has a failed prospect because of a lack of water, influenced by a hydroclimatic anomaly and/or human actions, this negatively affects the individuals' level of welfare, which they will feel as an impact; consequently, the situation will be perceived as a drought by this individual. For example, a prospect can be a farmer's choice to grow a certain crop (rather than another) in order to achieve greater gains or fewer losses depending on the context. This choice is made with the expectation that this crop will contribute to the achievement of the desired welfare level.

If, for instance, the prospect is to grow a water-consuming crop in a region characterized by low water availability, it can be an indication of the maladaptation and vulnerability of the individual. In this example, if a precipitation deficit occurs (hazard) and this negatively affects the chosen crops, resulting in unsatisfactory production (failed prospect), the individual will feel the impact and consider this event to be a drought. If, at some point, a critical mass (of people) experiences impacts, this might lead to the (official) declaration of a drought. This is the result of a complex interaction that includes many factors, such as those experiencing impact, their societal position, media exposure, power relations, and the political consequences of formally declaring a drought.

With respect to the real-world example of the farmer mentioned above, there were no failed prospects during the multi-year drought event, mainly because the farmer had a secure water source throughout this period; consequently, his desired level of welfare was never affected. Considering this, the simple answer that he gave us is coherent and logical: he did not experience impacts related to the negative hydroclimatic anomaly (meteorological drought) that occurred in that region and, therefore, for him, a drought event never happened.

Considering drought as the collective impacts that emerge as failed prospects due to a lack of water makes it necessary to predict how individuals choose which prospects are more attractive. Prospect theory (PT) explains how individuals choose alternatives when the outcome is uncertain (Kahneman and Tversky, 1979; Tversky and Kahneman, 1986). This theory has been widely debated, especially in the socio-economic sciences. In the environmental sciences it has been applied in different contexts, such as reservoir operation (Bahrami et al., 2022), asymmetries in drought response (Tian et al., 2019), disaster management (Osberghaus, 2017), and irrigation water resources management (Wang et al., 2022).

One of the novel concepts that PT presented is that individuals in the real world do not maximize total wealth but instead react to possible or perceived gains or losses, which are emotional and short term. In other words, human beings do not necessarily seek to maximize their net benefit (or utilities) by always choosing the prospects that produce the highest level of benefit (Jones, 1999). To clarify this concept, we invite the reader to participate in a simple experiment (Kahneman and Tversky, 1979) consisting of choosing one of the options in the following two problems: (1) 80 % chance of winning USD 4000 or 100 % chance of winning USD 3000; (2) 80 % chance of losing USD 4000 or 100 % chance of losing USD 3000.

If you chose the second and first options in problems 1 and 2, respectively, you behaved like most people who participated in such an experiment (Kahneman and Tversky, 1979). This means that you presented risk-averse behaviour when the prospects were related to certain gains (problem 1) and risk-seeking behaviour when the prospects were related to certain losses (problem 2). The combination of these two patterns illustrates the idea presented by PT that the human tendency is to overvalue a certain (or highly likely) outcome, relative to outcomes that are probable (Kahneman and Tversky, 1979; Edwards, 1996; Levy, 1992). The problem indirectly illustrates another concept presented by PT, which is the "loss aversion" effect. This highlights the asymmetry in an individuals' perception of gains and losses; losses feel more "painful" than gains of equal magnitude feel "pleasurable". The consequences can be a preference for the status quo and the acceptance of riskier prospects to avoid certain losses (risk-seeking behaviour).

To define whether the outcome of a prospect is seen as a gain or as a loss, the prospect is compared with a reference point. The reference point can be influenced by what is experienced as the status quo or the "normal" situation but also by the way the decision problem is perceived (Kahneman and Tversky, 1984). This latter is called the "framing effect", whereby, depending on how individuals perceive and make sense of decision prospects in terms of gains or losses, they will show a tendency towards risk-averse or risk-seeking behaviour, respectively.

## 3 Socio-hydrology and prospect theory

We argue that the onset and propagation of human drought impacts (which we consider to be those that negatively affect an individual's welfare) and socio-hydrological phenomena (e.g. the reservoir effect and supply–demand cycle) can be explained through the lens of prospect theory. Figure 1 presents an overview of how prospect theory is related to socio-hydrology phenomena and drought emergence. The first concept to consider from PT is the reference point, which is the general term for the starting point from which to make different kinds of decisions. For drought assessment, we consider the reference point to be the minimum welfare level that individuals tolerate to feel satisfied and secure with the results of chosen prospects; deviations from this point are defined as a gain or loss. The environment guides the individuals' expectations regarding their level of welfare (reference point) and, in turn, the prospects chosen to achieve this desired level. For instance, the reference point can be influenced by environmental conditions such as water availability, which is related to aspects of food and water security, previous experiences (e.g. past drought events), community interactions (e.g. peer comparison), and socio-economic trends (e.g. production costs, goods prices, and local culture and governance). Importantly, the reference point will vary over space and time. For instance, a higher yield loss might be incorporated as acceptable in the reference point after years of drought or in a region with a consequent insecure water supply. The higher the reference point, the greater the potential for human drought impacts.

Once the individual has defined their reference point and delineated the desired level of welfare, they evaluate the decision prospects for achieving it. When faced with a situation of high water availability, individuals have more freedom to choose prospects that offer certain gains (risk-averse behaviour; blue cycle in Fig. 1), even if this promotes a reckless water use pattern and/or the development of activities that are not necessarily the most adapted to the environmental conditions of the region in which they are inserted. Successive gains associated with this behaviour will, in the short term, reinforce the selected prospect (short-term response; dashed arrow in Fig. 1) and, in the long term, raise the reference point. Levels of welfare below the reference point will be perceived as losses and will be avoided, even though the individual may have already experienced such levels as a gain in a previous situation (framing effect).

A series of successful prospects maintain the upward trend in the reference point, and this persists as long as the water resources to which the individual has access can sustain their water demand. This continues even if there is an impending drought situation, as a reduction in water consumption while the reference point is associated with satisfactory water availability can be framed by individuals as a direct decrease in welfare. When water is lacking and it is no longer possible to maintain the water consumption standards that the individual requires, this results in failed prospects and, consequently, drought impacts arise.

Initially, the drought situation is typically perceived as a loss, as we consider that it starts after a failed prospect. In the short term, individuals tend to focus on prospects that can at least prevent further losses, even if they were previously seen as risky (risk-seeking behaviour; orange cycle in Fig. 1). However, in the long term, if low water availability persists, it can cause individuals to adjust their expectations by lowering the reference point. In other words, individuals can be less impacted by water shortages simply because they accept suboptimal outcomes (e.g. lower agricultural produc-

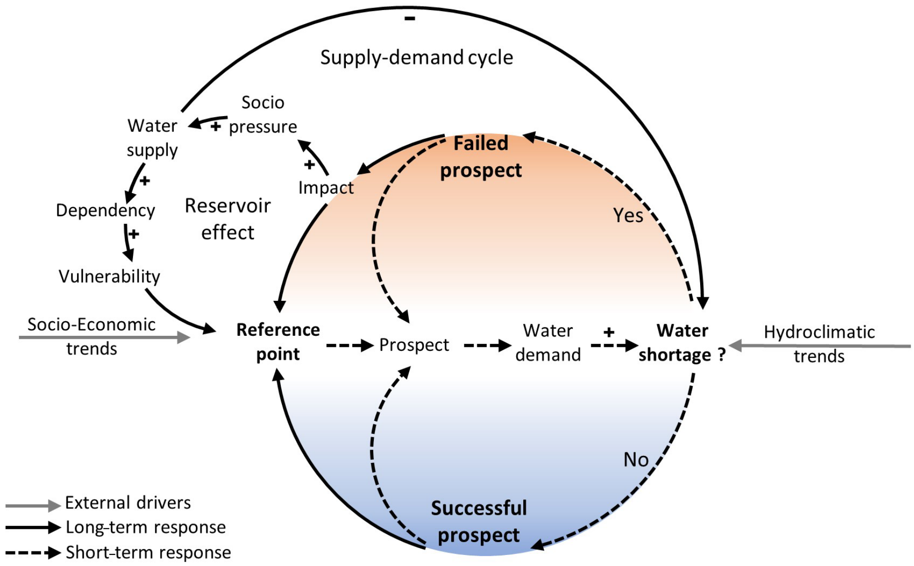


**Figure 1.** The cycle of human drought impacts. Our hypothesis emphasizes the centrality of the human component (starting from the reference point) in the emergence of drought impacts, with the individual as the primary scale. Moreover, the combination of how they are linked to the hydroclimatic trends and socio-economic trends results in the emergence of long-term socio-hydrological dynamics (reservoir effects and supply–demand cycle) that can be explained by concepts related to prospect theory, such as the reference point, the framing effect, and risk-averse (blue cycle) and risk-seeking (orange cycle) behaviour.

tion). Once this shift in the reference point occurs, individuals may no longer view the situation as a drought but rather as the "new normal".

As water availability gradually increases, either due to natural causes (hydroclimatic trends) or due to the expansion of water infrastructure, individuals are likely to shift away from their lower reference point and search for prospects that offer more certainty, thereby restarting the cycle anew (blue cycle in Fig. 1). We hypothesize that the demand to expand the water infrastructure can be related to situations in which individuals attribute the occurrence of drought impacts to low water availability without considering the suitability of their own chosen prospects under local environmental conditions. This behaviour can then, in the long term, result in social pressure to increase the water supply (e.g. reservoir construction and water transfer); when this demand is met, individuals can re-enter the cycle of increasing water consumption (blue cycle in Fig. 1). As the demand continues to rise, it can eventually offset the new maximum supply capacity. This can lead to more social pressure to increase the water availability, thereby creating a vicious cycle (supply–demand cycle in Fig. 1), greater dependency on water infrastructure, and greater vulnerability to drought events (reservoir effect in Fig. 1; Di Baldassarre et al., 2018).

## 4 Prospect theory and drought – insights from the Brazilian semi-arid region

The 2012–2018 meteorological drought in the semi-arid region of Brazil (SAB) is used as a practical example to highlight how prospect theory fits into the narrative of drought impacts as failed prospects. We focus on Ceará state, which is one of the sub-regions most impacted by this event. Figure 2 presents the percentage anomaly of annual precipitation relative to the long-term climatological average (1981–2011) for the SAB and Ceará state during the 2012–2018 drought event. The years prior to this drought were characterized by precipitation levels above the climatological average, which meant that most reservoirs in Ceará had stored volumes close to their maximum capacity.

This region has a historical susceptibility to drought events, and there has been observable change in the preparation and management of such disasters in recent times. This change is related to a shift from a "fighting against drought" perspective, which relied on hard solutions (such as significant investments in water infrastructure), to a "cope with drought" perspective, which relies on soft solutions (such as renewed focus on public policy towards adaptive measures and integrated water resources management) (Cavalcante et al., 2022; Medeiros and Sivapalan, 2020). Nevertheless, the high water availability experienced during the years prior to the 2012–2018 drought contributed to the support of high water demand production activities, such as rice paddies and irrigated fruit crops.

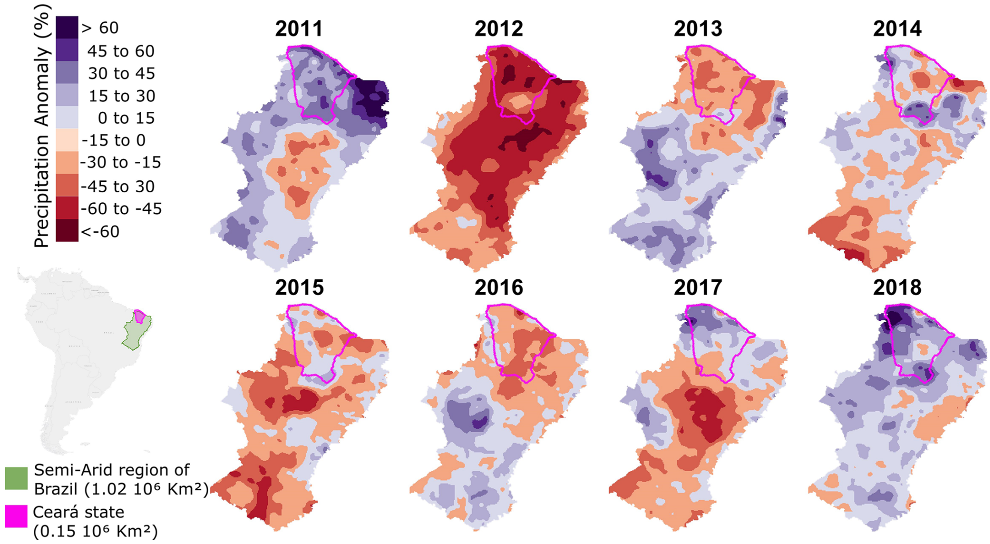


**Figure 2.** Precipitation variability in the semi-arid region of Brazil during the 2012–2018 drought. The percentage anomaly of annual precipitation relative to the long-term average (1981 to 2011) using the Climate Hazards Center InfraRed Precipitation with Stations (CHIRPS; Funk et al., 2015) dataset (available at https://www.chc.ucsb.edu/data, last access: 20 May 2023) is shown.

Before the occurrence of this drought, Ceará had been experiencing a gradual growth in dairy cattle farming, but this growth was intensified during the drought event. Farmers increasingly started to see this activity as a prospect more adapted, from a local perspective, to droughts because it guaranteed a source of perennial income and served as a capital reserve (part of the herd could be sold at any time). Furthermore, it is considered that cattle farming is less dependent on locally produced inputs and on the spatio-temporal heterogeneity of the precipitation regime when compared with rainfed crops.

Figure 3 presents an overview of prospect theory applied to the Ceará study case. We hypothesized, based on field interviews, that periods of high water availability provided a certain stability to farmers who depended on rainfed crops (short-term positive response; first dashed blue arrow in Fig. 3). However, the following and more frequent occurrence of intense meteorological drought events caused them to experience consecutive production losses (failed prospects) which led the individuals to view the exclusive production of rainfed crops as a riskier prospect (short-term negative response; dashed red arrow in Fig. 3) and dairy production as a prospect that would avoid further losses (long-term negative response; red arrow in Fig. 3). One of the barriers that made individuals view this activity as unattractive or risky was the low and volatile price of a litre of milk in the local market. This changed when associations of small dairy producers were created, and they started to have more bargaining power within the dairy industry. Due to this new socio-economic trend, individuals began to see cattle farming as a prospect more adapted to drought and that promoted more certain gains (short-term positive response; second dashed blue arrow in Fig. 3). This is further evidenced by farmers who had already adopted this activity due to previous drought events and who continued to favour this kind of prospect in later periods of greater water availability (long-term positive response; second blue arrow in Fig. 3).

The expansion of dairy production in Ceará has resulted in an increase in small (informal) reservoirs to support forage production and to provide water for livestock consumption. In some regions, the high concentration of small reservoirs has decreased the surface runoff connectivity of the watershed, impacting the recharge of large reservoirs downstream that serve multiple purposes (Ribeiro Neto et al., 2022). As a result, the persistence of this hydrological impact affects the region's water availability, as the large reservoirs remain at reduced water storage levels for longer periods, which in turn can influence individuals' perception of water security (component of welfare) and, consequently, their definition of the reference point.

Interviews with farmers and agricultural extension officers regarding desirable reservoir volumes illustrated the concept of the reference point and how it can vary according to previous experiences. Interviews revealed that volumes were consistently around 5 % during the 2012–2018 drought; the lower water availability had become the status quo (or the reference point). Therefore, increased volumes up to 20 % of capacity were celebrated, as they were considered gains, even though such a level would have been considered a loss prior to the multi-year drought.

Based on the case study presented here, we identified situations that can be analysed using the loss aversion effect. Loss aversion is related to the attempts of individuals to adapt to drought, aiming, in general, to avoid greater losses through

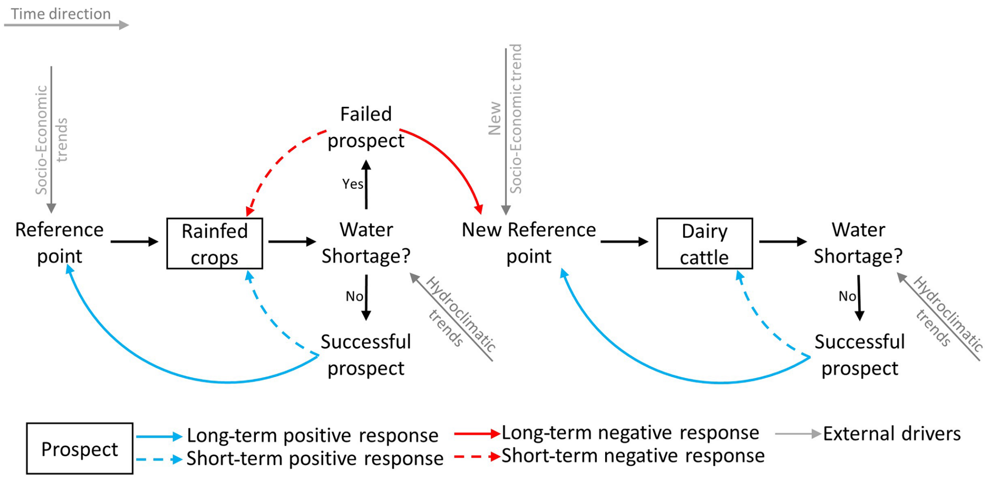


**Figure 3.** Prospect theory in socio-hydrology applied to the Ceará study case.

measures that reduce water demand. We observed that one of these adaptations was the search for hybrid bovine breeds, resulting from the crossing of local breeds that are resistant to drought with European breeds that have a higher milk production. These hybrid breeds were already known by the local farmers, but they were long seen as not worth the investment, due to the high cost of acquisition. However, during the 2012–2018 drought, an acceleration in herd replacement with these hybrid breeds was observed. Many farmers decided to sell part of their herd to raise capital to invest in these hybrid breeds. They realized that it would be safer, in a scenario of low water availability, to maintain a smaller but more productive herd.

The increase in the number of wells in Ceará between 2012 and 2018 is another practical example that illustrates the loss aversion effect. For Ceará, this alternative water supply can be considered a risky prospect, as it presents high implementation costs and is associated with uncertainties regarding whether a viable water resource will be found for exploitation, either due to the water quality (brackish groundwater is common) or because crystalline geology often provides low yield. Therefore, it was perceived that individuals in this region who chose to install wells were willing to take more risks to avoid greater losses.

## 5 Simulating prospect theory effects – applications, challenges, and opportunities

The lack of studies considering patterns of co-evolution between hydrological processes and human dynamics within a hydrological system has mainly been because human dynamics have been considered insignificant and due to the low spatio-temporal resolution at which hydrological models originally operated. Implicitly, the idea existed that it would be impossible or unfeasible to implement anthropogenic actions as an intrinsic component of the hydrological cycle has been successively refuted by various studies related to drought assessment (Wens et al., 2021, 2019; Van Oel et al., 2012; Streefkerk et al., 2023; Wens et al., 2020; Bakarji et al., 2017; Van Oel et al., 2018).

The presented concept of (human) drought impacts as failed prospects provides a different perspective to incorporate the socio-hydrological characteristics of a region into drought analysis. Drought impacts as failed prospects can especially contribute to the improvement and development of drought monitoring and early-warning systems, socio-hydrological characterization, drought risk analysis, forecast/reanalysis of drought events, and the development of public policies for the mitigation and prevention of drought impacts. On the other hand, prospect theory has limitations – mainly related to the lack of explanatory power regarding how decisions are made, especially with respect to the definition of an individual's reference point and how this is influenced by the environment and the full range of affective and emotional states.

We consider that, when applied to drought assessment, the reference point is related to the minimum level (with respect to well-being) required for an individual to feel satisfied with the outcome of the chosen prospects. To represent this concept, it is necessary to study the evolution of human dynamics, mainly related to how water and land have been used over time by individuals in the hydrological system. Agent-based models (ABMs) are a promising framework for these kind of studies, as they allow explicit probabilistic simulation of human decision-making with the ability to respond, learn, and adapt to variations in environmental states and other agents (Schrieks et al., 2021). Moreover, ABMs have been successfully applied in socio-hydrological studies, combined with hydrological and/or agricultural models (Wens et al., 2021, 2019; Streefkerk et al., 2023). These types of analyses often require expertise and methods usually associated with the social sciences, such as interviews, workshops, companion modelling, and serious games (Massuel et al., 2018; Acosta-Michlik and Espaldon, 2008; Pouladi et al., 2019; van Duinen et al., 2016). This further underlines that drought assessment studies are conceptually interdisciplinary and, therefore, require solutions beyond those associated only with the natural sciences.

The possibility of explaining the occurrence of a drought event through the use of prospect theory endorses the importance of the human component in drought assessment, in addition to fostering new discussions on this topic. The core concept presented here advocates for a greater focus on the human component within drought assessment studies and places the emergence of human impacts as a precursor to the disaster. This viewpoint contrasts with the methodological approach of numerous studies in which drought events are analysed only considering the spatio-temporal variability in hydrometeorological variables, disassociated from the human component (Kchouk et al., 2022). Furthermore, the reference point concept provides a theoretical basis for considering drought impacts dynamically, in contrast to the static vision on drought impacts that is now often encountered (e.g. in drought assessment studies). Prolonged drought impacts lead to a change in the individuals' perception of drought occurrence: the impacts become the new normal situation and are, therefore, no longer experienced as impacts. Moreover, we argue that the concept of drought impacts as failed prospects reinforces the perspective that drought is first and foremost a socio-hydrological phenomenon that materializes in the form of a disaster.

## 6 Conclusions

We demonstrated the application of the concept of drought impact as a failed prospect. We argue that the collective perception of individuals regarding the emergence of drought impacts plays a crucial role in both the magnitude and the occurrence of this kind of disaster. We argue that prospect theory, which originates from behavioural economics, can provide a new angle to analyse the human dimensions of drought by including the individual's perception at the centre of the analysis. We presented the idea that drought impacts arise when individuals perceive that they have not achieved their desired welfare level due to water shortage. This observation emerged from the multi-year drought event that occurred in the semi-arid region of Brazil from 2012 to 2018, which was used as a case study. Applying prospect theory and its concepts, such as the reference point, helped us understand that individuals' perceptions of drought impact emergence vary over time. In simpler terms, prolonged water shortage periods can be seen as a new normal situation. Consequently, individuals may no longer experience impacts, as their welfare expectations align with the new water availability condition. Other concepts, such as the loss aversion effect and framing effect helped us understand the tendency of individuals to change their water consumption pattern only when this resource is lacking as well as their tendency to adapt to drought events.

This understanding offers the opportunity to bridge the knowledge gaps related to the human influences on drought events by acknowledging the individual human dimensions. We showed the potential of prospect theory with respect to addressing interdisciplinary methodological and conceptual gaps between natural and social sciences. The hypothesis presented here can contribute to the identification of new socio-hydrological phenomena and improve the understanding of phenomena already described in the literature. Furthermore, our insights contribute to the demand for a change in perspective regarding how studies related to disasters involving hydrometeorological extremes, especially drought events, should be conducted, providing new ideas about the importance of representing the human component. We also support the idea of introducing more balance between the "socio" and "hydro" components in studies related to drought assessment, in which more interdisciplinarity should be sought, as hydrology and meteorology alone simply do not provide the means to understand human dynamics within the (socio-)hydrological cycle.

*Data availability.* The precipitation dataset used in Fig. 2 is available from https://data.chc.ucsb.edu/products/CHIRPS-2.0/global_monthly/ (Funk et al., 2015).

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