HESS Opinions: Drought impacts as failed prospects

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Abstract. Human actions induce and modify droughts. Yet, there remain scientific gaps regarding how hydrological processes, anthropogenic dynamics, and individuals' perception of impacts are intrinsically entangled in drought occurrence and evolution. This poses the challenge of developing ways to evaluate human behavior and its pattern of co-evolution with the hydrological cycle - mainly related to water use and landscape modifications. We propose that prospect theory can explain the emergence of drought impacts. This behavioral economic theory is predominantly applied to explain decision-making processes under uncertainty. We argue that it can also contribute to explaining socio-hydrological phenomena such as reservoir effects. From the prospect theory perspective, impacts are considered as failed welfare expectations ("prospects") due to water shortage. A shifting baseline after prolonged exposure to drought can therefore mitigate experienced drought impacts. This new approach can contribute to bridging natural and social sciences perspectives for more integrated drought management that takes into account the local context.

1 Introduction

During fieldwork conducted by the authors of this paper in the Semiarid region of Brazil (SAB), a farmer was asked how the historic 2012-2018 multi-year drought event (Marengo, 2020; Cunha et al., 2019a, b, 2018) 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) and how this in turn influences individuals' own perceptions of disaster occurrence ("Drought? What drought?"). This is in line with the concept of "Drought in the Anthropocene" (Van Loon et al., 2016b), 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 to normal conditions. This is not restricted to a physical cause (e.g., a negative anomaly in rainfall), 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 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 to study drought events and other disasters at scales that are commonly disregarded. For example, by starting from the individuals in the hydrological system that experience impacts, and by evaluating the decisions 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., 2016b; Di Baldassarre et al., 2019; Tian et al., 2019), gaps remain regarding the relationship between hydrological hazards (e.g., drought), the perception of impact of this hazard, and 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 determines the magnitude and the very occurrence of a drought event, this being related to both environmental and socio-economic factors. Using Prospect theory (Kahneman and Tversky, 1979), stemming from the field of behavioral 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, then the relationship between socio-hydrology and Prospect theory to finally present how this can be applied to real 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 possible prospects those 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, and is therefore directly related to their vulnerability and resilience. We propose that when an individual has a failed prospect because of a lack of water, either influenced by a hydroclimatic anomaly and/or human actions, this negatively affects the individuals' level of welfare, which they will feel as an impact and consequently the situation will be perceived as a drought by this individual. For example, a prospect can be the choice a farmer makes to grow a certain crop rather than another, 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 aimed 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 maladaptation and vulnerability of the individual. In this example, if a precipitation deficit occurs (hazard) and this negatively affects the chosen crops, resulting in an unsatisfactory production (failed prospect), the individual will feel the impact and consider this event to be a drought. If there is, at some point, a critical mass that experiences impacts, this might lead to the (official) declaration of a drought. This is the result of a complex interaction including many factors: those experiencing impact, their societal position, media exposure, power-relations, the political consequences of formally declaring a drought, et cetera.

Returning to the real example of the farmer mentioned above. He never had any failed prospects during the multi-year drought event, mainly because he had a secure water source throughout this period and consequently his aimed level of welfare was never affected. Considering this, the simple answer 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 make it necessary to predict how individuals choose which prospects are more attractive to follow. 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 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 benefits, or utilities, by always choosing the prospects that produce the highest level of benefits (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 $4000 or 100% chance of winning $3000; 2) 80% chance of losing $4000 or 100% chance of losing $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 aversion" behavior when the prospects are related to certain gains (problem 1) and "risk seeking” behavior when the prospects are 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). 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 the preference for the status quo and the acceptance of riskier prospects to avoid certain losses ("risk seeking” behavior).

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 aversion or risk seeking behavior, 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 the 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. Fig. 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 as the minimum welfare level that individuals tolerate to feel satisfied and secure with the results of chosen prospects, and deviations from this are defined as a gain or loss. The environment guides the individuals’ expectations regarding their level of welfare (Reference point), and with that for choosing the prospects to achieve them. 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, 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 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 delineates 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 aversion behavior, blue cycle 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 where they are inserted. Successive gains associated with this behavior, in the short term, will reinforce the selected prospect (short term response, dashed arrow Fig. 1) and, in the long term, raise the Reference point. Levels of welfare below the Reference point will be perceived as losses and 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 keep the upward trend in the Reference point, and this is maintained 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, since the 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 behavior, orange cycle 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 production). Once this shift in Reference point occurs, individuals may no longer view the situation as a drought, but rather as the "new normal".

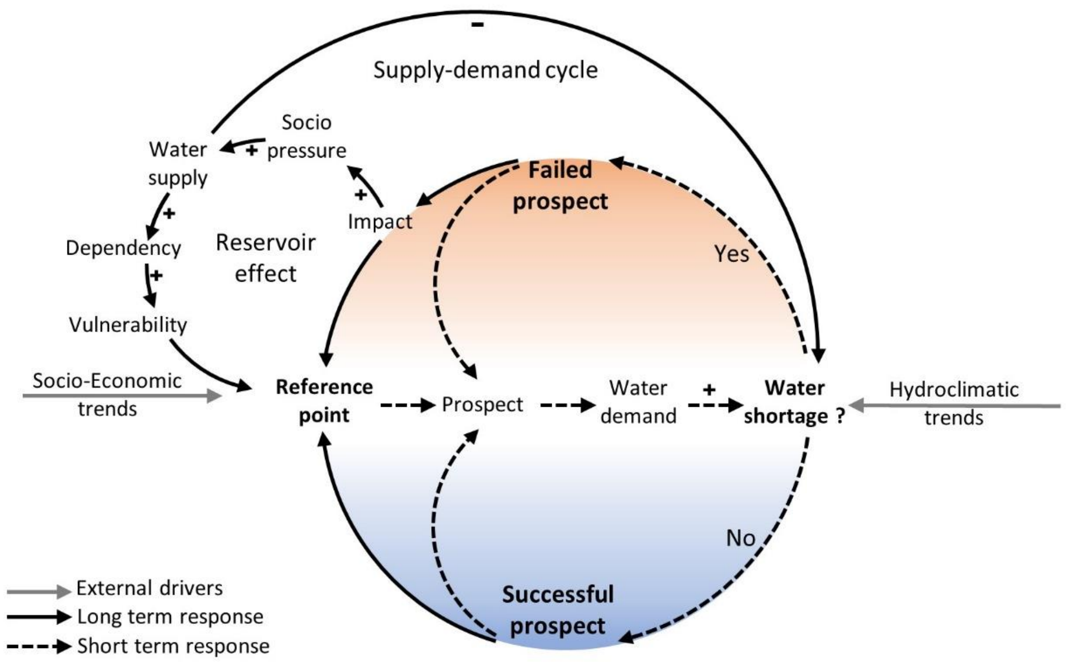

Figure 1. – The cycle of human drought impacts. Our hypothesis emphasizes the centrality of the human component (starting from the Reference point) in the emergence of drought impacts with the individual as the primary scale. Moreover, the combination of how they link to the hydroclimatic and socio-economic 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: Reference point; Framing effect; Risk aversion (blue cycle) and Risk seeking (orange cycle) behavior.

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, which restarts a new cycle (blue cycle Fig. 1). We hypothesize that the demand to expand the water infrastructure can be related to when individuals attribute the occurrence of drought impacts to low water availability without considering the suitability of their own chosen prospects in local environmental conditions. This behavior can then, in the long term, result in social pressure to increase water supply (e.g. reservoir construction and water transfer), and when this is met, individuals can re-enter the cycle of increasing water consumption (blue cycle, 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 water availability, thereby creating a vicious cycle (Supply-demand cycle, Fig.1), greater dependency on water infrastructure, and greater vulnerability to drought events (Reservoir effect, Di Baldassarre et al., 2018, Fig.1).

4 Prospect theory and drought - insights from the Brazilian semiarid region

The 2012-2018 meteorological drought in the Semi-Arid region of Brazil (SAB) is used as a practical example that highlights 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. Fig. 2 presents the percentage anomaly of annual precipitation relative to the long-term climatological average (1981-2011) of 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 in recent times, there has been observable change in the preparation and management of such disasters. 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 adaptative 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 productive activities, such as rice paddies and irrigated fruit crops.

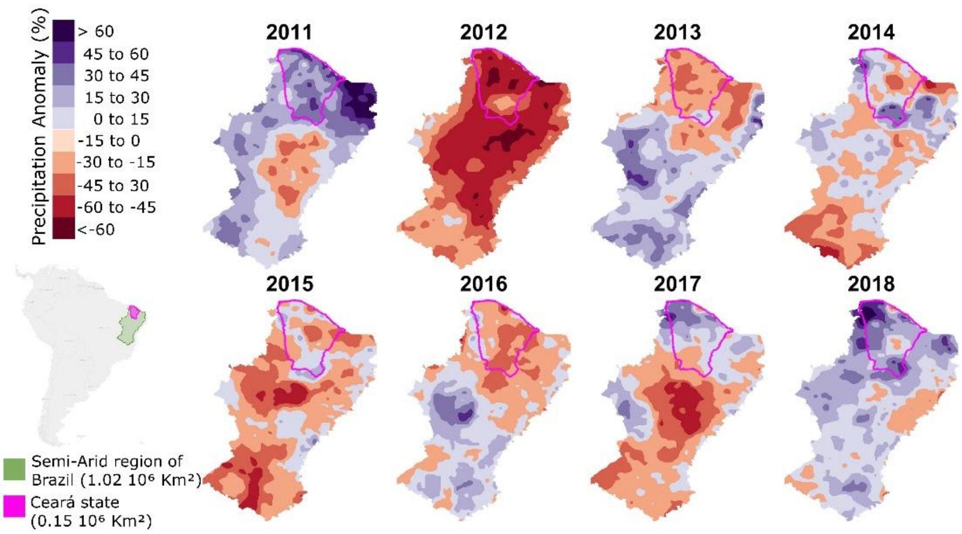

Figure 2. Precipitation variability in the Semi-Arid of Brazil during the drought 2012-2018. Percentage anomaly of annual precipitation relative to the long-term average (1981 to 2011) using the Climate Hazards center InfraRed Precipitation with Stations (CHIRPS, Funk et al., 2015) dataset available on https://www.chc.ucsb.edu/data.

Before the occurrence of this drought, Ceará had already been experiencing a gradual growth of dairy cattle farming which was intensified during this event. Farmers increasingly started to see this activity as a prospect more adapted, from a local perspective, to droughts because it guarantees a source of perennial income and serves as a capital reserve (part of the herd can 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 to rainfed crops.

Fig. 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 blue dashed arrow, 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, red dashed arrow, Fig. 3) and dairy production as a prospect that would avoid further losses (long term negative response, red arrow, Fig. 3). One of the barriers that made individuals view this activity as unattractive or risky was the low and volatile price of a liter 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. In this new socio-economic trend, individuals began to see cattle farming as a prospect more adapted to drought and which promotes more certain gains (short term positive response, second blue dashed arrow, Fig. 3). This is further evidenced by farmers who had already adopted this activity due to previous drought events and that continued to favor this kind of prospect even in later periods of greater water availability (long term positive response, second blue arrow, Fig. 3).

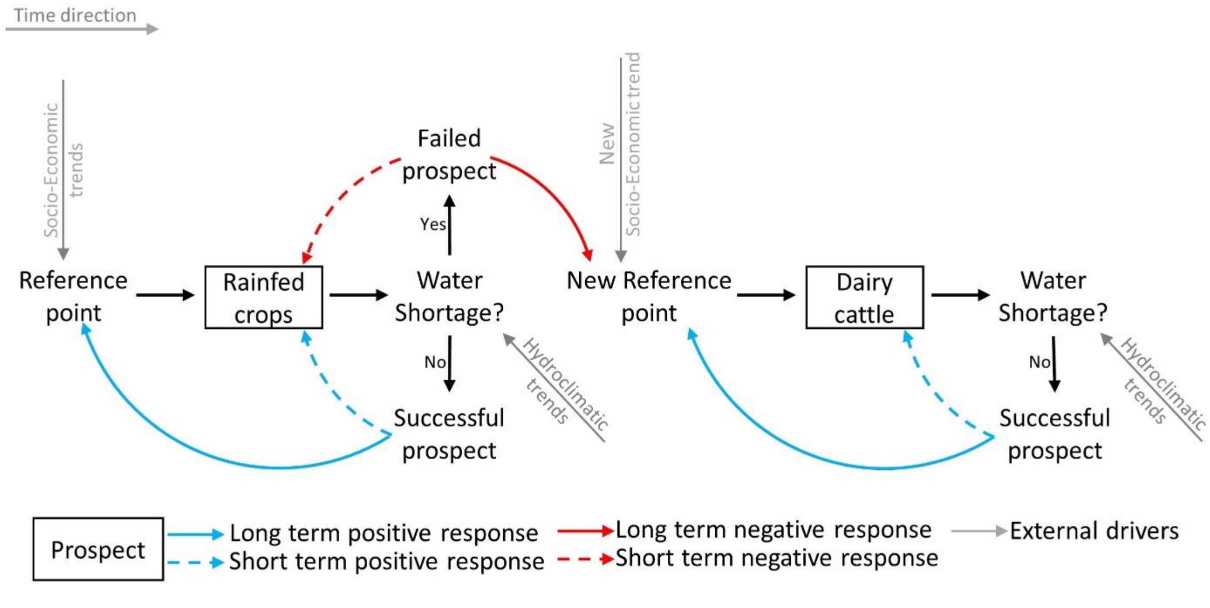

Figure 3. Prospect theory in socio-hydrology applied to Ceara study case.

The expansion of dairy production in Ceará has resulted in the increase of small (informal) reservoirs to support forage production and to provide water for livestock consumption. In some regions the high concentration of small reservoirs 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, since the large reservoirs remain at reduce 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, because 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 analyzed 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 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 by 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 2012-2018 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 to whether a viable water resource will be found for exploitation. Either because of the water quality (brackish groundwater is common) or because crystalline geology often provides low yield. Therefore, it is 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 considering patterns of co-evolution between hydrological processes and human dynamics within a hydrological system was mainly because human dynamics were 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, which 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/re-analysis of drought events, and support the development of public policies for the mitigation and prevention of drought impacts. On the other hand, the prospect theory has limitations - mainly related to the lack of explanatory power on how decisions are made, especially related 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 of individuals' well-being 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 (ABM) 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, it has 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, besides bringing 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 analyzed only considering the spatio-temporal variability of 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: in drought assessment studies. Prolonged drought impacts lead to a change in the individuals' perception of drought occurrence, the impacts have 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.

There is already an understanding and acceptance of the concept of "human-induced", "climate-induced" and "human-modified" droughts (Van Loon et al., 2016a) that explore the main causes that trigger different types of drought events. The drought impacts as failed prospects concept does not refute these terminologies, since they are useful in indicating the main forces that are disrupting the hydrological system, nor does it invalidate established concepts of definition or classification of drought such as 'agricultural drought' and 'hydrological drought', as these terminologies relate to the main types of impacts that individuals suffered during the analyzed event.

The hypothesis presented here can contribute to the identification of new socio-hydrological phenomena and improve the understanding of others already described in the literature. Furthermore, it contributes to the call for a change of perspective on how studies related to disasters of hydro-meteorological extremes, especially drought events, should be conducted, bringing new ideas about the importance of incorporating the human component in these issues. Finally, we also support the idea of bringing more balance between the "socio" and "hydro" component in the 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.

Competing interests

The contact author has declared that none of the authors has any competing interests.

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