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Drought in the Anthropocene

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Drought management is inefficient because feedbacks between drought and people are not fully understood. In this human-influenced era, we need to rethink the concept of drought to include the human role in mitigating and enhancing drought.

The current multiyear California drought has severely affected both environment and economy. In this area where water supply is highly artificial, water storage in reservoirs and groundwater abstraction provide water during dry periods, but also increase evaporation and decrease groundwater levels, and thereby exacerbate the drought. In contrast, management responses, such as water transfer and water saving measures, alleviate drought conditions[1]. The ongoing California drought clearly demonstrates how strongly water and society are intertwined during drought periods.

Severe droughts in human-dominated environments, as experienced in recent years in California, Brazil, China, Spain and Australia, cannot be seen as purely natural hazards. Anthropogenic changes to the land surface alter hydrological processes including evapotranspiration, infiltration, surface runoff, and storage of water and in this way affect the development of drought. That this anthropogenic influence is not taken into account is reflected in the disconnected management of surface and groundwater and the sometimes perverse effects of water rights and insurance[2].

Here we point out the key gaps in our understanding of human influences on drought and potential feedbacks between drought and society. We argue that, in order to manage drought effectively in our profoundly human-influenced era, the Anthropocene, we need to acknowledge that human influence is as integral to drought as natural climate variability.

A watershed moment

Drought research has a long history in both the natural and social sciences. Hydrologists and climate scientists have made significant progress in understanding the physical processes underlying drought propagation[3]. At the same time, economists, geographers and sociologists have studied the impacts and perceptions of drought[4]. However, these fields have operated in relative isolation without considering the complex interactions between natural and human processes.

Often people are considered as passive recipients at the end of the propagation cascade from meteorological drought via soil moisture drought to hydrological drought, but in fact people actively influence drought propagation (Fig.1). The traditional unidirectional approach to drought research leads to poor prediction and management of this complex interdisciplinary phenomenon. Instead we call for drought research to explicitly consider the multi-directional relationship between natural drought processes and the role of people.

Redefining drought

Drought is a complex, multifaceted issue[5]. Traditionally, most definitions have viewed drought as a natural phenomenon and regarded human-made water shortage as a separate process[6,7]. Although it is important to be aware of the different causes of water shortage for the purpose of mitigation and adaptation, this separation is not always useful for drought monitoring and management. Drought monitoring is designed to observe a lack of water in different parts of the hydrological system without attributing it to climate anomalies or human factors. And the impacts of drought to socioeconomic and ecological systems are the result of this lack of water that is caused by the complex interaction of natural and anthropogenic processes.

We therefore propose to broaden the definition of drought to include water shortage caused and modified by human processes. Drought is then simply an exceptional lack of water compared to normal conditions. Although the anthropogenic influence has not been explicitly recognised, this revised definition of drought is effectively already in use in drought monitoring and impact analysis. It is also important to define drought as an episodic phenomenon as distinct from water scarcity, which reflects a long-term imbalance between water demand and water supply[3].

A drought can manifest itself in below-normal soil moisture levels (soil moisture drought) or below-normal river discharge, groundwater, lake or reservoir levels (hydrological drought). Without heavy modification of the water cycle by human activities, soil moisture drought and hydrological drought are caused by meteorological anomalies and modified by catchment properties such as land cover, soil, and geology[3]. However, in most of the world today, drought has both natural and human drivers – for example, surface and subsurface water abstraction – and is modified by land properties reshaped by human activities – for example, urbanisation and deforestation (Fig.1). Human influences can be recognised explicitly in the definition of drought by distinguishing between climate-induced drought, human-induced drought and human-modified drought (Fig.2). The recent drought in Brazil, for example, is a human-modified drought, influenced by deforestation, urbanisation and reservoir construction[8].

Drought research in the Anthropocene

Human activities modify the hydrological processes underlying drought propagation (Fig.1). For drought prediction, we need to understand how a precipitation deficit is transformed into soil moisture drought and hydrological drought and how human activities are affecting this transformation positively and negatively. Despite some studies on the effects of land-use change on low streamflow, there are still many open questions. Answering these questions requires development of new statistical and modelling tools to analyse existing data, as well as the collection of qualitative and quantitative datasets on water use and land and water management.

Attribution of the causes of drought is crucial to determine whether drought management should focus on adaptation to climate-induced drought or mitigating the actions that lead to human-induced drought. Making this separation requires combining observations and models in virtual model experiments, in which groundwater levels or streamflow in the absence of human influences can be assessed[7,9] (Fig.2).

Regardless of the underlying causes, soil moisture drought and hydrological drought have impacts on society and economy that are indirect and confounded by a range of other factors. For instance, the impacts of recent droughts in California and China on farmers' profits are difficult to disentangle from the impacts of policy changes on water rights and access, water pollution, political instability, and commodity prices[2]. Furthermore, socio-economic and ecological impacts are not independent (Fig.1). Industries such as agriculture, forestry and recreation depend on ecosystems and the mitigation of socio-economic impacts can aggravate environmental impacts[2,9].

A better understanding of how the public perception of drought[4] and adaptation strategies[2] influence these impacts is also needed. To assist this, large drought impact databases are being compiled, such as the Drought Impact Reporter (droughtreporter.unl.edu) and the European Drought Impact report Inventory (www.geo.uio.no/edc/droughtdb) for the US and Europe, respectively. Together with improved data analysis methods, such databases should provide insight into the relationships between drought and its impacts.

Society is not a passive victim of drought. Instead, society responds to drought, both in the short term - by extracting more water and implementing water saving measures - and in the long term - by increasing water storage through infrastructure, and by changing policy and regulations (Fig.1). Perhaps surprisingly, the resulting feedbacks on soil moisture, streamflow and aquifer water levels are rarely quantified. For example, water saving measures and a new groundwater law will come into effect over the coming years in California[1], but it is essentially unknown how much these measures will alleviate current and future droughts. Frameworks for analysing socio-ecological systems[8] and multi-disciplinary modelling tools[10] could assist in answering these questions if applied specifically to drought events.

Importantly, long-term societal responses to drought alter the baseline (the normal water level for a region) against which droughts are assessed, as do long-term changes in climate and landscape. We need to integrate the natural and social sciences to anticipate such changes and to evaluate pathways for drought adaptation. This will give us the tools to predict drought in the future.

Crossing the watershed divide

Drought research should no longer view water availability as a solely natural, climate-imposed phenomenon and water use as a purely socio-economic phenomenon, and instead more carefully consider the multiple interactions between both. First steps have been made in the broader field of hydrology in which there has been a recent research shift towards considering interactions between the hydrological cycle and society[10,11].

We can also draw inspiration from two success stories in drought management where natural and human processes were considered together. In Australia, a combination of water technology, water pricing and education implemented during a 9-year drought in the 2000s proved to be successful in alleviating drought conditions[12]. And following a drought in the 1990s in the Spanish Jucar basin, a water resources system model combining hydrology, engineered water abstractions and stakeholder perspectives was developed that contributed to the maintenance of residual river flows throughout a subsequent drought event.

We call upon drought researchers and managers to include all of drought's complex, interrelated processes as the natural world and human society become increasingly entangled in the Anthropocene.

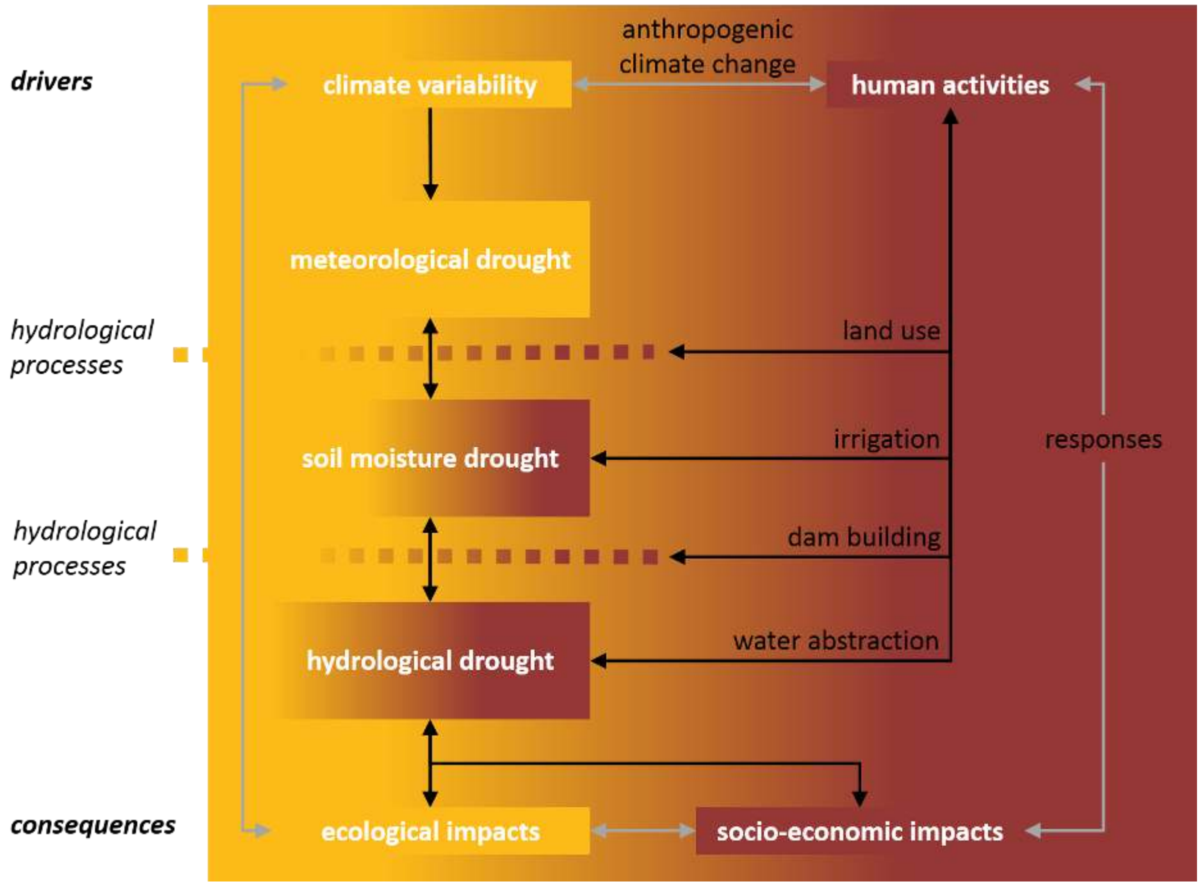

Figure 1: Drought propagation in the Anthropocene. The propagation from meteorological drought to soil moisture and hydrological drought is initiated by climatic (left; yellow) and human (right; red-brown) drivers. Drought is modified by hydrological catchment processes (dotted lines) that are altered by human activities (black arrows). The resulting ecological and socio-economic impacts initiate responses, which in turn result in changes to the human influence on drought and the climate variability (grey arrows).

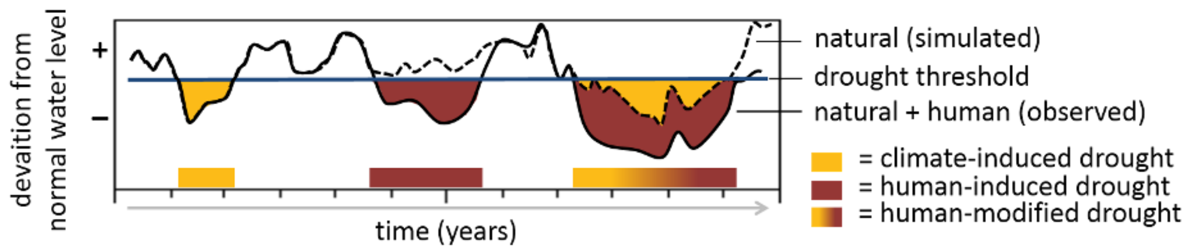

Figure 2: Hypothetical schematic of the distinction between climate-induced drought, human-induced drought and human-modified drought. Observed water levels (black line) that are influenced by both natural and anthropogenic factors are compared to simulated water levels from virtual model experiments[7] (dashed line) that consider only natural drivers. Note that human-modified drought can be aggravated or alleviated with respect to the natural situation.

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