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The health and well-being effects of drought: assessing multi-stakeholder perspectives through narratives from the UK

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Abstract
The global literature on drought and health highlights a variety of health effects for people in developing countries where certain prevailing social, economic and environmental conditions increase their vulnerability especially with climate change. Despite increased focus on climate change, relatively less is known about the health-drought impacts in the developed country context. In the UK, where climate change–related risk of water shortages has been identified as a key area for action, there is need for better understanding of drought-health linkages. This paper assesses people's narratives of drought on health and well-being in the UK using a source-receptor-impact framing. Stakeholder narratives indicate that drought can present perceived health and well-being effects through reduced water quantity, water quality, compromised hygiene and sanitation, food security, and air quality. Heatwave associated with drought was also identified as a source of health effects through heat and wildfire, and drought-related vectors. Drought was viewed as potentially attributing both negative and positive effects for physical and mental health, with emphasis on mental health. Health impacts were often complex and cross-sectoral in nature indicating the need for a management approach across several sectors that targets drought and health in risk assessment and adaptation planning processes. Two recurring themes in the UK narratives were the health consequences of drought for 'at-risk' groups and the need to target them, and that drought in a changing climate presented potential health implications for at-risk groups.

Keywords Drought · Health · Narratives · Mental health · Outdoor recreation · At-risk · Climate change

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1 Introduction

The existing literature on drought and health focuses largely on developing country contexts (Stanke et al. 2013). Similar studies are starting to emerge in developed countries (Vins et al. 2015; Vos 2017), but there remain limited empirical findings and understanding about relationships between drought and health in these countries. In the context of findings which show implications for human health from extreme weather events due to climate change (IPCC 2015), and that increased drought risk under climate change has implications for at-risk individuals, communities and health systems (Ebi and Bowen 2016), the threat of climate change further compounds the need for addressing this gap in understanding in developed countries. This paper presents findings from the Drought Risk and You (DRY) project, which is concerned with evidence to support better drought risk decision-making in the United Kingdom (UK) through interdisciplinary perspectives and approaches. DRY involved seven case-study river catchments in Scotland (Eden), Wales (Ebbw) and England (Bevills Leam, Don, Fowey, Frome and Pang) (Fig. 1). Catchments were selected to provide gradients (hydro-meteorological; rural-urban) and variation in characteristics such as geology, topography, land use, demography, drought experiences and culture (Table 1) (see Blake and Ragab 2014). The project developed a science-narrative approach using drought risk modelling, experimentation through grassland and agronomic mesocosms and future scenario modelling, to stimulate narratives of different stakeholder perspectives. Perceived health and well-being implications of drought were specifically investigated through narratives to address the paucity of evidence about health consequences of UK drought.

Narrative approaches allow participants to be 'storytellers', presenting unique opportunities to explore relationships, contexts and specificities of embodied and personal experiences (Dahlstrom 2014; Constant and Roberts 2017). Narratives therefore provide specific exemplars enabling them to translate scientific data into more comprehensible 'life-like' formats, as well as translate local knowledge into policy-relevant data (Paschen and Ison 2014). According to Morris et al. (2019), stories provide narrative structure with varying degrees of essential features including an identifiable character, plot and setting. Hence, narratives can serve as both knowledge building and communication tools, encapsulating local knowledge as a form of social capital. In their data gathering role, narratives provide rich and detailed local experiences and perspectives and have been previously used to highlight drought impacts on farmers in Australia, including impacts on health and well-being (Anderson 2009). Narrative and cultural-driven analyses of drought from the perspective of domestic gardens and water use have revealed indirect implications for mental health (Askew and McGuirk 2004; Chappells et al. 2011; Head and Muir 2007). In the UK, narrative research in flood risk management concluded that lay knowledge is vital for sustainable flood memory, integrating individual, collective, communicative and archival memory to build local knowledge for action (McEwen et al. 2016; Holmes and McEwen 2020). A narrative approach is applied in this paper to explore local stories of experiences and future expectations of drought impacts on health and well-being.

The following sections give an overview of the context of the study, in terms of the literature on drought, the drought-health nexus and linkages in the UK between drought and climate change. Section 2 presents the research design. Section 3 presents the results, and Section 4 provides discussions and conclusions of the work presented, including its contributions to current understanding of drought impacts in the UK.

South-North		West-East	
Fowey	1436mm	Fowey	1436mm
Ebbw	1456mm	Frome	792mm
Don	1009mm	Pang	695mm
Eden	799mm	Bevills Leam	630mm

Fig. 1 Location of the seven DRY project river catchments across Britain (Catchment boundaries are © UKCEH 2020)

1.1 Drought characterisation

Drought is a slow-onset hazard, with effects accumulating slowly over substantial periods, and no clearly defined beginning and ending (Wilhite et al. 2014). Drought impacts are often non-structural, spread over large geographical areas and have far-reaching economic, environmental

Table 1 Summary of the physical and sociodemographic characteristics of the seven study catchments

Case catchment	Sociodemographics	Physical characteristics	Hydrology and water management	Drought experience*
Fowey at Restormel	Rural villages; 50% summer population increase (local economy heavily dependent on tourism)	Moderate relief; Bodmin Moor granite, Devonian slates and grits 64% grassland; 18% woodland;11% arable/horticultural; < 1% settlements	River flows dominated by rapid surface runoff Heavily affected by public water supply abstraction including surface water reservoirs Water demand highly seasonal	1976, 1977, 1984, 1990, 1995
Frome at Frenchay	Spans urban, suburban and rural, city (Bristol), town (Yate), villages; ethnically diverse; large business parks and hospital	Moderate relief; sandstones, mudstones and clays; superficial gravels; 48% grassland; 5% woodland; 21% arable/horticultural; 11% urban	River flows dominated by rapid surface runoff	1976, 1990, 1995, 2005, 2011
Pang at Pangbourne	Rural; town (Pangbourne), villages; agriculture	Chalk downland; 28% grassland; 18% woodland; 45% arable/horticultural; 1% settlements	River flows dominated by slowly responding groundwater Chalk aquifer recharge and abstraction West Berkshire Groundwater Scheme operated by Thames Water/EA at times of extreme drought to augment river flows with abstracted groundwater	1975–1977, 1991–1992, 1995–1997, 2004–2006, 2010–2012
Bevills Leam at Tebbits Bridge	Rural villages; agriculture; tourism (boating and nature reserves); up to 37 km^2 of wetland restoration; 2 national nature reserves (Holme/Woodwalton Fens)	Low relief with significant areas of catchment below sea level Peat soils underlain by clay; 5% grassland; 5% woodland; 85% arable/horticultural; 2% settlements The Great Fen project	Highly managed pumped drainage system with high/low-level drains Water level management balances winter flood relief, water storage for irrigation and water levels for boating navigation Significant abstraction (2 million m^3) for agricultural spray irrigation Imported public water supply	1965, 1973, 1976, 1990, 1997, 2003, 2011–2012
Ebbw	Spans urban and rural: Ebbw Vale and Brynmawr conurbation, plus other towns (e.g. Abertillery, Blackwood, Risca)	Moderate-permeability, mainly coal measures High-permeability bedrock, 0.0%; moderate-permeability bedrock,	Small water supply reservoirs in uplands Some groundwater abstractions in valley	1964, 1972, 1976, 1978, 1984, 1989–1990, 1995–1996, 2002,

Table 1 (continued)

Case catchment	Sociodemographics	Physical characteristics	Hydrology and water management	Drought experience*
	Mixed land use 40% grassland, upland heath at highest elevations in north; 15% forest, mainly in lower valley to south Significant urban development (> 10%) in valleys	81.8%; low-permeability bedrock, 2.6%; generally high-permeability superficial deposits, 0.5%; generally low-permeability superficial deposits, 0.5%; mixed-permeability superficial deposits, 14.7%	Drainage water from old coalmines can also influence flows. Reservoirs in catchment affect runoff. Runoff reduced by public water supply abstraction Runoff influenced by groundwater abstraction and/or recharge	2003, 2005, 2006 and 2010–2011
Don at Hadfield's Weir	Spans urban and rural: city (Sheffield), towns (Stocksbridge; Penistone), villages; ethnically diverse; SMEs dominate Sheffield, plus manufacturing base; rural agriculture/tourism	Mixed geology 36% grassland; 16% woodland; 6% arable/horticultural; 19% moorland; 13% urban	Upper catchment has several reservoirs which substantially impact flow regime. Runoff significantly reduced by public water supply and industrial and/or agricultural abstraction Runoff influenced by groundwater abstraction and/or recharge Runoff increased by effluent returns	1975–1976, 1990, 1995–1996, 2011–2012
Eden at Kemback	Rural: town (Cupar), villages; Scottish stakeholders: water supply; whisky distillery; market gardening	Gently sloping and low-lying sandstone, limestone and igneous 29% grassland; 12% woodland; 52% arable/horticultural	Abstractions for irrigation and public water supply (sandstone aquifer) Groundwater abstractions, effluent returns and small reservoirs in the headwaters	1973, 1974, 1976, 1989, 1995, 2006

*Since 1961

and social consequences (Ebi and Bowen 2016). The complexity of drought has made it useful to consider droughts according to specific disciplinary perspectives (Wall and Hayes 2016). Meteorological drought defines drought through precipitation deficiency over a given period (Wilhite et al. 2014). Agricultural drought results in insufficient support for plant water demands (Ebi and Bowen 2016). Hydrological drought, often monitored by water companies, shows a deficiency of surface and subsurface water supplies compared to average conditions (Wilhite et al. 2014). Finally, socioeconomic drought exists where droughts lead to societal or environmental impacts (Wall and Hayes 2016). This concept of drought emphasises relationships between water and human activities and is manifested due to overlapping of all drought perspectives (Wall and Hayes 2016). In addition to natural drivers, human activities influence water inputs, outputs and storage, and therefore modify the propagation of different drought types, and can even be the cause of drought in some circumstances (Van Loon et al. 2016).

Droughts differ in three essential characteristics: intensity, duration and spatial coverage, with the latter influenced by geology and whether the drought is groundwater or surface water driven (Wilhite et al. 2014). In the UK, groundwater droughts of long duration (18 months or more) affect chalk catchments in the south and east (Marsh and Turton 1996). These pose the greatest threat to water resources and supply if groundwater resources fail to be replenished during dry winters (Marsh et al. 2007). Surface water droughts (spring, summer and autumn of a single year) tend to affect the north and west where there is dependence on surface waters (Marsh and Turton 1996; Marsh et al. 2007). Marsh et al. (2007) highlighted that spatial variations in drought severity can be significant across and within regions, illustrating how difficult and complex it is to define drought across the UK, and then identify and quantify its various impacts.

1.2 The drought-health nexus

Systematic reviews (Stanke et al. 2013; Vins et al. 2015; Vos 2017) have provided an overview of health and drought in various contexts. Stanke et al. (2013) highlighted direct public health impacts of reduction in potable water supply, with increases in diseases such as diarrhoea (Wales in 1976; Haiti in 1977 (Burr et al. 1978)), scabies and conjunctivitis (Haiti in 1977; Thacker et al. 1980). Although the mechanisms were complex, diseases seemed to spread due to lack of, and reduced quantities of, water for handwashing and personal hygiene. These were mostly reported in developing countries (Vos 2017). Additionally, health risks arose when low water levels allowed for concentration of pathogens, notably *Escherichia coli* (Effler et al. 2001) and cholera (Bradley et al. 1996) in Africa and leptospirosis in the USA (Jackson et al. 1993). Drought can also allow concentrations of harmful chemicals—especially due to sewage effluents, surface runoff and animal faeces—to increase as quantities of water in rivers, lakes, reservoirs and groundwater sources decrease (Kuntz and Murray 2009; Wall and Hayes 2016). Reduced water quality because of drought has been cited in outbreaks of waterborne diseases such as cholera, skin rashes, blisters, vomiting, headaches and diarrhoea predominantly in developing countries (Stanke et al. 2013).

Although agriculture has a history of adapting to various shocks (Wreford and Adger 2010), if significantly affected by drought, food security and nutrition can be disrupted. The causal mechanisms are usually quite complex involving several underlying variables (e.g. socioeconomic status and resilience/adaptive capacity of the agricultural sector), which increase risk factors during drought. Drought and other natural disasters are usually just a trigger for nutrition-related health impacts (Stanke et al. 2013). Such impacts are often more visible in

developing countries—including malnutrition (Singh et al. 2006, 2008), micro-nutrient deficiencies (e.g. vitamin A) (Wolde-Gabriel et al. 1993) and consumption of anti-nutrients (e.g. aflatoxicosis due to mould-affected food) (Krishnamachari et al. 1977; Williams et al. 2004). Little evidence exists of food security or nutrition-related health impacts relating to drought in developed countries (Stanke et al. 2013).

Mental health and drought have been the focus of significant research in developed countries, particularly Australia (Edwards et al. 2015; Vins et al. 2015), with relatively less in developing countries—though Wutich and Ragsdale (2008) discusses mental distress from water insecurity in the context of Bolivia and Keshavarz et al. (2013) discuss the psychological and social impacts of drought in rural Iran. Defined as 'a state of well-being in which an individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and is able to make a contribution to his or her community', mental health is the foundation for well-being and effective functioning for individuals and communities (Herman et al. 2005, p. 31). Mental health and mental illnesses are determined by multiple and interacting social, psychological and biological factors (Herman et al. 2005). Mental health impacts associated with drought were found to be most severe for farmers and their families through loss of livelihoods from reduced agricultural output. When livelihoods are threatened, anxiety and depression can develop, with potential increases in domestic abuse, violence and suicide. Indicators such as distress or 'emotional consequences of drought' were generally associated with negative mental health impacts. Negative mental health outcomes were more associated with rural communities (Friel et al. 2014; O'Brien et al. 2014). One Australian study found no significant differences between genders in terms of stress but that males reported higher psychological distress (Austin et al. 2018). Environmental degradation of properties and local environment due to drought has also been linked to depression and anxiety (Vins et al. 2015).

Air-borne and dust-related diseases due to drought were also identified (Stanke et al. 2013; Vos 2017). The Central United States 'Dust Bowl' of the 1930s led to thousands of peoples' deaths from dust pneumonia in the Great Plains, and it shows the implications of drought on air quality and health (Wall and Hayes 2016). Limited studies exist on health impacts of windblown dust in drought. Research on desert dust and health indicates that those with pre-existing respiratory conditions were most 'at-risk' to the health effects of dust (De Longueville et al. 2010). At-risk groups include older people, with lower immunological capacity and deterioration in general health due to ageing processes, and the very young, whose lungs and airways have not yet fully developed (Goudie 2014). In the USA, there were reports of worsening respiratory conditions (e.g. asthma) with increasing dust during drought periods (Vos 2017), although further research is needed for other long-term conditions. Studies have implicitly linked drought-induced dust with coughing and wheezing in Canada (Gomez et al. 1992) and valley fever in California (Zender and Talamantes 2006). Research in the USA found that severe drought increased risk of mortality but decreased risk of respiratory admissions amongst older adults (Berman et al. 2017).

Other impacts identified included vector-borne diseases predominantly in developing countries (e.g. dengue, malaria, chikungunya). In the European context, there is increasing concern about the spread of vector-borne disease under conditions of climate change, e.g. outbreaks of mosquito-borne disease (Semenza and Suk 2018). Outbreaks of necrotising fasciitis in Austria (Hirk et al. 2016) and West Nile virus throughout Africa and Europe (Marcantonio et al. 2015) were strongly linked with summer drought where water deficit and heat combined. Other reported impacts such as physical injuries due to drought conditions, health effects through heatwaves associated with summer droughts, wildfire and damages to infrastructure were aligned with developed countries. Drought-

health impacts in developed countries were less extensive, perhaps due to less exposure to underlying risk factors because of infrequent droughts, availability of resources (Stanke et al. 2013), enabling policy and legislative frameworks and resilient infrastructures (Bryan et al. 2019). It should be emphasised the results reported in many studies illustrated that underlying risk factors in developing countries interacted with drought conditions to exacerbate existing challenges (Ebi and Bowen 2016). Therefore, drought-related morbidity and mortality were reported more in developing countries.

1.3 Drought, climate change and the UK context

Droughts are projected to increase in frequency and severity over the coming decades in the UK (Watts et al. 2015), making the understanding of perceived health impacts an emerging research priority. UK climate change projections show a general trend of increasingly wet winters and drier summers, and overall warmer temperatures in all seasons (Water UK 2016). River and lake water quality are projected to decline because of higher water temperatures, lower river flows and increased algal blooms in summer months (Watts et al. 2015), which could also increase health effects.

The UK Committee on Climate Change Risk Assessment (UKCCRA) identified water shortages as one of six urgent priority climate risks requiring more action (Committee on Climate Change 2017). According to the report, demand for water could be more than 150% of the available resource in many UK catchments by the 2050s under some scenarios. Under these scenarios, it will not be possible to abstract water up to 25% of the time without causing ecological damage in many catchments. This could require more frequent water restrictions including temporary use bans (TUBs) and limits on abstraction. The impact on health of heatwaves has been identified as an urgent priority (Committee on Climate Change 2017). The average number of hot days per year and the chance of a severe heatwave are increasing and projected to rise further with climate change. Consequently, heatwave events like 2003 are projected to increase in the UK by the 2040s (Water UK 2016). This is particularly important with regard to the health of at-risk groups. Hence, in addition to flooding, drought and heatwaves will progressively present wide-ranging challenges for different parts of the UK.

Studies of previous UK droughts tend to focus on meteorological and hydrological variables (Marsh and Turton 1996; Kendon et al. 2013), indices for drought hazard assessment (Phillips and McGregor 1998; Vidal and Wade 2009) and perceptions of drought causes and management strategies (Chappells et al. 2011; Dessai and Sims 2010; Bryan et al. 2019). Vos (2017) reported no UK-based studies in the review for OECD countries whilst Stanke et al.'s (2013) global systematic review reported findings from one UK study, highlighting lack of a drought-health focus in the UK. This 1976 study compared incidences of diarrhoea and vomiting amongst school children in drought-affected areas with water restrictions with those in areas without restrictions (Burr et al. 1978). Other UK-based studies mentioned by Stanke et al. (2013) were those on health impacts of wildfire (Finlay et al. 2012) and private water supplies (PWSs) (e.g. Said et al. 2003) and were not drought specific. PWSs are provided by someone, other than a statutorily appointed water undertaker (Said et al. 2003). In 2017, there were 72,869 PWSs in the UK (Drinking Water Inspectorate, DWI 2017), supplying 1% of the population (DWI 2019). Unlike the small number of tests (0.04%) from public water supplies that failed European Union (EU) and national standards in 2016, 4.2% of PWS tests in England and Wales failed to meet these standards (DWI 2017). Quality of PWSs can be exacerbated by dry weather increasing chances of disease outbreak. Dry weather was a contributing factor for outbreaks of infectious diseases in PWSs in 1992 and 1995 (Said et al. 2003).

To date, there has been no significant research focus on drought and health in the UK. Outbreaks of cholera and successive droughts since the 1890s led to regulatory reforms and investment strategies, paving the way for a reliable water sector (Bakker 2000; Medd and Chappells 2007). In this context, more recent drought periods, such as 2005–2006, 2010–2012 and 2018, are considered 'near-miss' events and less severe impacts (Bryan et al. 2019). The evidence base for health risk associated with drought is hence limited due to the relative infrequency of drought episodes, and methodological difficulties in ascertaining exposure and attribution of health outcome. Nonetheless, climate change may mean future droughts present more significant health and well-being implications.

2 Research approach

2.1 Analytical framework

An analytical framework was developed to guide thematic assessment of narratives on the health impacts of UK droughts. Analysis of the literature on drought-health linkages revealed several sources and receptors of drought-health impacts, which we have incorporated into a source-receptor-impact analytical framework (Fig. 2). The framework drew on systems approaches such as the driver, pressure, state, impact and response (DPSIR) framework, which has been successfully applied in flood research (e.g. Wallingford 2002) for representing systems and processes that lead to impact. This presents an excellent starting point, although there are also unique aspects to drought situations. The main aim of such models is to identify the proximal and distal causes of unwanted situations and identify where in the system specific actions can be targeted. To take a very simplified example, a *driver* of climate change may be economic growth, the *pressures* are increases in greenhouse gas emissions, the *state* may be increased drought, the *impact* might be farm failure and mental health problems for rural communities and the *response* may be public investment in rainfall retention schemes. We recognise that any model can never be a complete representation of a complex system but it can be a 'problem-framing tool' (Morris 2010, p. 39) that helps people think more clearly about the downstream impacts of climate change on human health and well-being (Morris 2010). In the current research, this provided a way we could think more clearly about the complex narratives that were being elicited.

The DPSIR is, however, a high-level framework and analysis; using it can lack details of the proximal pressures and states, as well as details about who exactly is being impacted and in what way. Given the unique narrative approach adopted here, it was more appropriate to enlarge on these aspects of the framework in a 'source', 'receptor', 'impact' approach. The sources here were the key factors associated with the drought, e.g. heatwaves concurrent with summer droughts, or those that develop due to drought conditions and include reduced water quantity, water quality (physical, chemical and biological), compromised hygiene and sanitation, nutrition and food security, as well as air quality changes and disease-spreading vectors. Each of these sources will affect one or more 'receptors', which are the recipients of an impact originating from a source. These can be different groups of people or animals. 'Impacts' are the effects or outcomes that a recipient experiences due to exposure to a source and include diseases and threats, as well as opportunities and benefits, to their physical and mental health. The current adaptations to more traditional frameworks, such as DPSIR, were made in recognition of both the unique challenges of drought which, as far as we are aware, had not been considered previously using such an approach, and also the more in-depth qualitative nature of the data which provided unique opportunities and insights, especially with respect to the

range of receptors affected. It thus puts people at the heart of the model and avoids some of the issues that have been found with the application of the DPSIR model in other contexts, where shortcomings in terms of dealing with multiple attitudes and definitions of issues are identified (e.g. Svarstad et al. 2008).

2.2 Narrative approach

To apply the framework, we analysed drought-related narratives derived from application of qualitative and narrative methods with 41 participants from diverse backgrounds (e.g. water, environmental and public health professionals, allotment holders, farmers, private sector and community residents) by DRY team members across the seven case-study river catchments. Some participants were selected whilst others emerged through snowballing with these initially identified participants, and through various engagement activities. Table 2 (Electronic Supplementary Material, ESM) provides further information about the participants, and Fig. 2 shows their spatial distribution. We used semi-structured and narrative interviews, story sharing and creation of short video stories and collection of short audio-recorded stories (micro-narratives) at events such as festivals and river walks to build a repository of stories (Roberts et al., submitted, in which details of narrative methods are provided). Ethical clearance was obtained through the lead research organisation.

All data sources were audio recorded and transcribed. Story transcripts were thematically coded by two team members using QSR NVivo software (to assess consistency qualitatively). The coding results were discussed with the wider team, followed by further coding to determine the final themes. The framework was utilised to code emerging themes from the narratives by sources, receptors and impacts (see Fig. 3). These were mapped into a matrix with the sources in columns and the receptors in rows, filled with numerical references representing the participant/narrator who detailed the impact or expected impact. The effect of impacts were positive (+), negative (−) or neutral (=) (ESM Table 3). Cognitive mapping was used to explore themes and connections across sectors and catchments, and as a way of triangulating the themes identified in the transcript analysis with other team members and stakeholders. ESM Table 3 shows how these were mapped. Some of the receptors hypothesised did not emerge in these interviews in terms of the health impacts—e.g. the economic impacts on health were not discussed. Further sectoral-level narratives for a range of sectors are available from the DRY utility (www.dryproject.co.uk).

3 Perceived sources, receptors and drought impacts on health and well-being

Each of the identified sources of drought-health effects is presented, with discussion of the impacts on key receptors in subsections below.

3.1 Drought, water quantity, hygiene and sanitation

3.1.1 Water supply users

Communities, at-risk groups and businesses represent specific water supply users with differential effects and impacts. Household- and community-related vulnerabilities regarding water

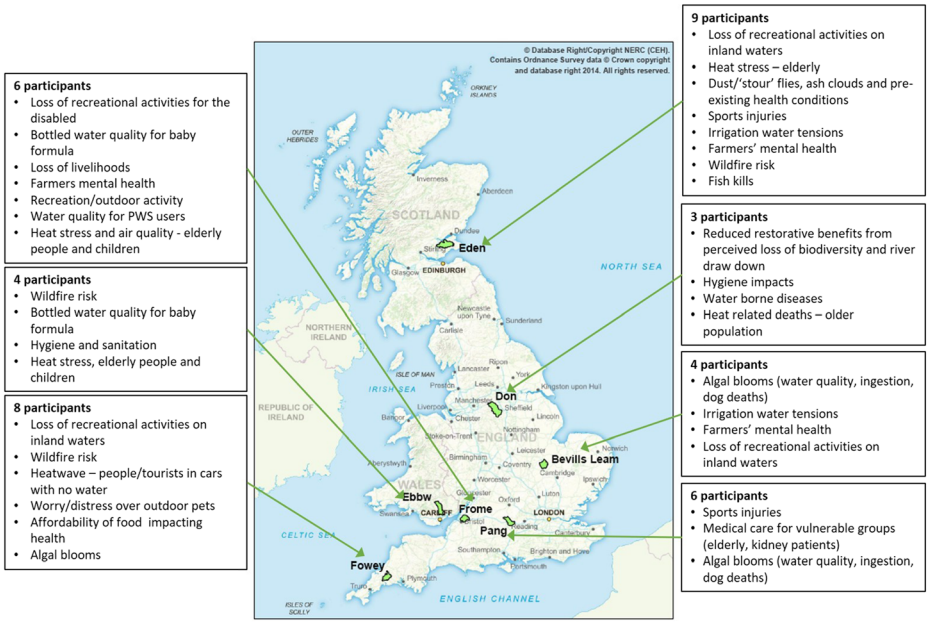

Fig. 2 Spatial distribution of participants and major narratives across catchments (Catchment boundaries are © UKCEH 2020)

supply were highlighted in terms of mental health and well-being due to worry or stress about water supply. Worry may be over affordability of water during scarcity or for specific uses (see Q#1, ESM Table 4).

There were also discussions about implementation of TUBs, such as hosepipe bans, as a response to a socioeconomic drought. Some participants mentioned that not being able to water gardens can be distressing due to emotional attachments to gardens. Gardening is an important feature of life and well-being for many in the UK (Buck 2016). Hence, this loss of amenity and perceived ability to interact with the environment can present negative well-being implications as found in other developed countries (Allon and Sofoulis 2006; Askew and McGuirk 2004; Vins et al. 2015). Also, there is potential for disruption to social cohesion when cooperation to TUBs is not universal. Participant #07 from the Pang catchment relayed an unfortunate story of a TUB-related conflict and death in Australia (Q#2, ESM Table 4). Although no fatalities were reported by participants, TUB-related conflicts have arisen in the UK:

> The Police went by and asked an old guy why he was using a hosepipe during a ban and he turned round and sprayed the police and they couldn't not prosecute him P#08, water resources specialist, Pang catchment.

When it comes to accessing water for irrigation during drought, farming communities also displayed stressful tensions and conflicts around drought-related water restrictions as discussed by farming participants in the Eden and Bevills Leam (Q#3–4, ESM Table 4).

In some instances, analogies of similar events, such as burst pipe incidents, were used to offer insight into drought-related problems. One such analogy highlights potential for an increase in scald injuries observed when boil water notices are issued for affected communities:

> There have been local no-water situations because there's a burst pipe or the pressure's gone…. Whenever you have a boiled water notice, there's a risk of scald injuries (particularly to children) P#17, CPHM, Eden catchment.

The need to maintain water supply for medical care during drought was a recurring theme. People with pre-existing health conditions requiring constant water supply (e.g. kidney dialysis) were identified as at-risk in several narratives:

> Another massive problem for the Water Authority was people on dialysis machines. People mostly use them from six in the evening to six in the morning so we had to get them into hospital as we couldn't guarantee the water supply P#22, retired water company employee, Ebbw catchment.

Business participants generally had no contingency plans for drought, and most were unfamiliar with 'no water' situations. Again, burst pipe analogies offered insight into the likely effects of, and responses of, businesses to a 'natural' drought. The example below highlights the potential public health threat posed by the catering industry in times of supply interruption:

> You'd be surprised how many businesses quite naturally want to continue trading when they haven't got a proper water supply. How people manage around that, washing hands, keeping food safe, could become a very big issue P#04, public health specialist, Ebbw catchment.

Whilst this may not typically present a problem over short timeframes, reduced sanitation over prolonged periods could impact public health, especially if businesses sourced inferior quality alternative sources of water. It was also recognised that if businesses were not able to maintain services in drought, mental health impacts associated with loss of livelihoods may arise as seen elsewhere (Stanke et al. 2013; Vins et al. 2015; Vos 2017).

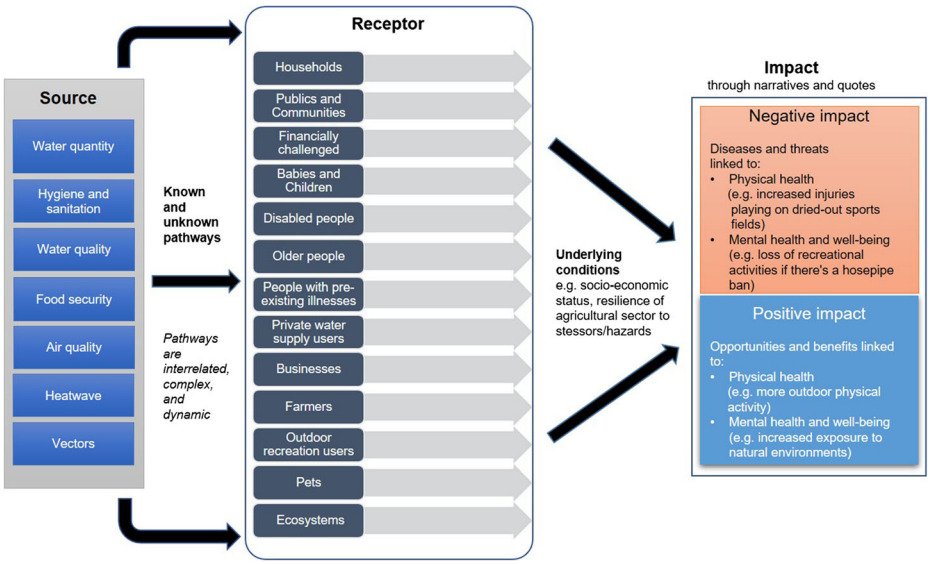

Fig. 3 The source-receptor-impact analytical framework applied in the analysis of drought-related health and well-being effects

3.1.2 Private water supply users

Private water supply (PWS) users were viewed as vulnerable in times of water scarcity because their water supplies often have limited redundancies and are not subject to the same quality regulations as public supplies (Smith et al. 2006). Participants expected that loss of supply could have both mental and physical health implications for PWS users. Participant #10 tells more below:

> There are tens of thousands of people across the UK who rely upon their own private water supplies…many of those sources…are at risk of drying out…. And at times like that, it can be quite stressful for people because they then have to make alternative arrangements…or for them physically to transport water…. And that would certainly result in stress as well as, possibly, an impact on their livelihood P#10, UK water policy expert.

PWS users in the USA have had physical health effects due to hauling water during drought (Wall and Hayes 2016). Whilst several of our participants on PWSs said they had never run out of water, one reported that some PWS users in NE Scotland had been supplied with tankers of water by the local water company (as a non-statutory gesture) during the 2018 drought.

3.1.3 Outdoor recreation users

Millions regularly take part in outdoor physical activities (walking and other moderate-vigorous-intensity recreational physical activities) for recreation and exercise in the UK (White et al. 2016). Use of both land- and water-based environments for recreation provides physical and mental health benefits. Reduced water quantity during drought can have both negative and positive implications for access to outdoor recreation activities. Studies on precipitation and physical activity show that, in general, lower precipitation increases activity (Chan and Ryan 2009), although more recent evidence suggests there may not be a strong impact in the UK (Elliott et al. 2019). The health and drought studies we reviewed did not consider this component in their assessments, although it is sometimes identified in climate change risk assessments.

Inland water-based activities (e.g. canoeing, kayaking) were likely to be negatively affected by low water levels:

> At Siblyback [a lake in Cornwall]…we have a good link with a respite disability centre…they have a small (well, medium-sized) sailing boat that they go out and use and, of course, if the water level is out and they can't get the sailing boat in close, then they can't use it P#21, wildlife manager, Fowey catchment.

This story reveals how low water levels can result in loss of physical activity that forms an essential part of the long-term health and well-being of a specific at-risk group. In the absence of a suitable alternative, they will experience reduced health and well-being. Others relayed stories about the challenges of navigating canals in low water during past droughts, but there were no reports of accidents or fatalities, as reported in other countries (Wall and Hayes 2016).

On the other hand, coastal water–based physical activities were expected to increase as conditions become ideal for activities such as sailing and swimming (see Section 3.2.2). For the same reasons, some land-based physical activities were expected to increase during summer drought:

> …drought makes it easier to get people out and about in the outdoors…and appreciate the natural environment P#26, wildlife manager, Eden catchment.

Drought conditions were expected to increase access to some natural environments, thereby strengthening potential positive physical and mental health outcomes. Nonetheless, participants also highlighted that certain land-based activities such as field sports might become dangerous during drought:

> In a drought the ground is rock hard and dry…you're falling over on a surface that is effectively as hard as concrete. You get more beaten up when you're playing sport in times of drought P#07, water efficiency manager, Pang catchment.

When TUBs are implemented, fields cannot be watered which increases their hardness and danger for sporting activities. Furthermore, it was also noted that, if people lost access to outdoor physical activities, this could affect their physical health and well-being. Therefore, despite the expectation that people would participate in more outdoor physical activities, drier weather could result in negative health and well-being effects, especially when drought and heatwave coincide (Section 3.5). Figure 4 presents an overview of the impacts of drought on recreation and health.

3.1.4 Ecosystems

Reduced water quantity and overall drying conditions associated with drought can have implications for ecosystems and wildlife:

> As it has been quite a dry spring this year (2017), this has significantly affected the way the waders are nesting because they are not finding wet ground to feed in…there were lots of ponds that have dried up with all the frogspawn still in it P#26, wildlife manager, Eden catchment.

Others highlighted changes in predation, fish kills, vulnerability to viruses and failure of migratory fish to enter rivers from estuaries during drought. Participants highlighted that ecosystem impacts from drought could bring cascading risks for human health, particularly mental well-being:

> Drought focused in the future, I fear that that will have quite a serious impact on the rivers, the river Don catchment, and this may have knock on effects on how much benefit people get from the rivers as a resource, as a sort of green space, as an area where people can go and gain the restorative benefits that contribute towards their mental wellbeing P#02, environmental scientist, Don catchment.

Participants also lamented the challenge of balancing environmental water requirements with future demands for water in a changing climate and impact on ecosystem health.

3.2 Drought and water quality

3.2.1 PWS users and at-risk groups

There was consensus amongst water sector participants that drought would not significantly affect the quality of public water supplies and public health impacts would be minimised by the existing regulatory system (Q5–7, ESM Table 4). However, water quality of PWSs was felt more likely to present a public health threat to users, for example due to diminished bacteriological quality (Q#8, ESM Table 4). Water quality may be affected in other ways as seen from the 1976 drought:

> We did notice a slight change in the water from the spring. Before it was always quite clear water that would come through but we started to have little tiny, micro-fish coming in the water P#25, local resident, Frome catchment.

If water quality is compromised, PWS users must then seek alternative water supplies. Some participants feared that this might lead to the use of unregulated water, which in turn presents contamination risks, increasing potential for infection and disease outbreak.

Drought-related water quality concerns were also highlighted in relation to infants in a supply interruption analogy:

> We had some concern that the bottled water that was being provided by the water companies…was not of the right quality for them to be making up infant formula. It had too high quantities of dissolved salts within it which actually potentially was going to put the infants at risk if it was being made up over a long period of time P#14, public health specialist, Frome catchment.

This concern was also aired by another public health participant in the Ebbw catchment (Q#9, ESM Table 4), reiterating infant vulnerability to this conventional response under supply interruptions. Both were concerned about long-term impacts of this response if drought becomes more frequent. These risks are noted in national policies, but its communication to target audiences remains a problem. It is interesting to note that most concerns in terms of water quality came from experts experienced with PWSs, and that there may be a need for more research on the views of different publics.

3.2.2 Ecosystems and human health

Participants throughout the catchments were concerned about exposure of people and animals to water quality problems, such as algal blooms and reduced dilution during drought:

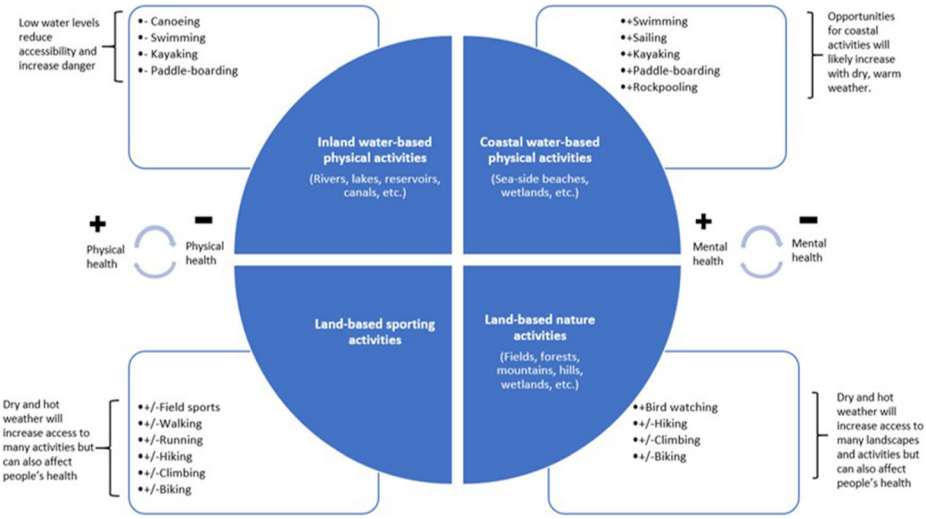

Fig. 4 Overview of drought impacts on recreation and health

> The concentration of pollutants is also a public health issue from the algal blooms, which is sometimes worse for pets P#27, natural heritage manager, Eden catchment.

Notwithstanding these issues, participant #10 believed that weather conditions related to summer drought could be beneficial for water quality and health. He suggested these benefits could be derived through improvement of wastewater treatment and reduction in numbers of combined sewer overflow (CSO) spills and that reduced CSO spills in drought can lead to improved bathing water quality, hence increasing some water-based recreational activities which would have positive health and well-being effects:

> Many of the UK's best bathing water results have come during periods of drought…. It also means that people are more likely to enjoy the seaside and that's good for their wellbeing P#10, UK water policy expert.

Whilst the literature is unclear about improved performance of wastewater treatment works during drought, the claim that reduced CSO spills improve water quality has been substantiated by studies outside the UK (Aukidy and Verlicchi 2017; Lau et al. 2002).

3.3 Food security

There were recurring stories about potato shortages in the 1976 drought, but drought was not expected to affect agriculture and ultimately food security now due to improved farming and storage techniques. However, if agriculture was seriously affected by drought, food prices were expected to change, which ultimately has dietary implications, particularly for those with lower incomes. These themes were particularly evident in the Bevills Leam, Eden and Fowey catchments where agriculture is important:

> The implications of our crops dying, is there might not be enough food in the shops. And a consequence of not enough food being in the shops is that prices might rise P#31, water resources manager, Bevills Leam catchment.

> The long-term impact of drought, particularly in the summer, could be quite significant for Scotland's ability to generate quantities of particular cereals, also soft fruits. There is an agricultural food link in that, and there are health links P#27, Eden catchment.

> If affordability of vegetables changes the impact on the population could be huge in terms of health P#18, public health specialist, Fowey catchment.

Nonetheless, some participants believed that the gap would be met through imports. This may not be sustainable in the future as climate change affects production in other parts of the world, disrupting food production (e.g. US maize production and 2012 drought). The UKCCRA identifies risk to domestic and international food production and trade as one of the top six risks requiring action (Brown et al. 2016).

3.4 Air quality

Air quality issues associated with drought are usually due to dust or wildfire (Section 3.5). Erosion can be a significant problem as experienced by participants in the Bevills Leam and Eden catchment who discussed 'Fen blows' and 'stours' (Q#10–11, ESM Table 4). The Fen Blow is a phenomenon where high winds whip up soil into the air around East Anglia (BBC

2013), and stours refer to events with dust in the air in Scotland. As well as air quality impact, these diffuse incidents can reduce visibility which might affect safety in the local area:

> If you have dry-ish but windy conditions…. Usually around March time when the fields have been worked but the vegetation hasn't really grown up yet so there is a lot of bare soil…. It has an impact on transport sometimes because I have seen roads blocked by dust that has blown into drifts across the road…. It impacts on people just living down there P#26, wildlife manager, Eden catchment.

More recently (2017), a dust event was cause for concern around the Eden catchment:

> In west Fife, there's an area of former lagoons…and a lot of the fly ash dried out and became entrained in the air…and you ended up with…basically clouds of coal fly ash dust being blown over a local community…people were worried about cancer risk and the long-term effects of inhaling the dust as well P#17, Consultant Public Health Medicine (CPHM), Eden catchment.

Despite media speculation about the negative health impacts of this incident, medical experts agreed that dust particles were unlikely to cause major health impacts (Q#12–13, ESM Table 4). Notwithstanding, they identified that those with pre-existing health problems could be affected even in short-term events. This narrative highlights the sometimes-unknown sources of perceived health concerns during times of water scarcity. These events may result in people staying indoors to limit exposure whilst sacrificing physical and mental health benefits of outdoor activities. These factors further increase the need to understand and highlight the linkages and impacts.

3.5 Heatwave

Heatwave and drought were often discussed together when participants spoke of drought, although droughts can occur outside times of increased temperature. However, drought and heatwave coincided in summer during the droughts of 1975–1976, 1995–1997 and 2003 (Wreford and Adger 2010) as well as 2018. Overall, warm weather means that people may increase participation in outdoor physical activities such as beach use (Elliott et al. 2018). However, in addition to the limiting and dangerous conditions of outdoor activities during drought (Section 3.1.3), heat exposure can further increase health risks during droughts. It was expected that summer drought would be more frequent and intense in the future, leading to more severe heat-related health impacts amongst at-risk groups. One participant discussed the cancellation of sporting events in schools due to fears of health effects of heat. Others discussed surviving London on the hottest day of the year and being stuck in a car or at home on a hot day with no water available due to supply interruption, with specific concern for older people.

The combination of drought and heatwave was also expected to lead to worsening air quality. This corresponds to evidence in the literature; for instance, ozone levels have been found to rise substantially on hot, sunny days and especially if anti-cyclonic conditions are met which trap emissions (Doherty et al. 2009). Again, certain groups were identified as potentially vulnerable receptors:

> So the higher levels which of course might associate with hot weather events…if you have got pre-existing respiratory or cardiovascular conditions not to put yourself in a position where you are likely to be exposed and increase your risk of either respiratory

> exacerbation or a cardiovascular event. And for particular sensitive receptors to stay indoors P#14, public health professional, Frome catchment.

Drought and heatwave were seen as catalysts for increasing wildfire risk. Participants in the Fowey and Eden catchments discussed this vulnerability during dry periods, and that there was a risk of people accidentally or deliberately setting fires:

> Because the floor was so dry, and needles of the pine were on the floor, one careless cigarette, especially on a windy day…the fires just went. It was a huge wildfire…and the fire was able to go and spread over a huge area P#30, firefighter, Eden catchment.

Smoke particles may present threats to health:

> Fine particles can cause sticking to the lung and they can damage the lungs…smoke particles are very, very small, they stick to the lungs P#05, retired medical practitioner, Don catchment.

Therefore, the combined effect of drought and heatwave could limit outdoor activities for certain vulnerable groups, which could present both physical and mental health issues. There may be particular impacts in schools, although these were not discussed in the interviews.

3.6 Vectors

There was limited awareness and understanding amongst participants of the linkages between drought and vectors. Participant #16 mentioned the increase in mosquitoes in Europe and the UK but was not explicit in terms of the drought link:

> Literally, there was a mosquito problem in the eastern Netherlands, and I think it is going to get worse in this country P#16, water and environmental specialist, Don catchment.

Precipitation changes have been found to affect the reproduction, development, behaviour and population dynamics of arthropod vectors, their pathogens and non-human vertebrate reservoirs (Brown et al. 2014). Research on mosquitoes shows not only that they are one of the most important arthropod vectors involved in transmission of various vector-borne pathogens (Stanke et al. 2013) but also that drought may lead to subsequent increases in mosquito numbers and disease outbreaks (Brown et al. 2014). There were also discussions about drought and midges, but it was unclear if and how drought would affect their spread (Q#14, ESM Table 4).

Linkages have been found between drought and outbreaks of diseases such as West Nile virus, the presence of disease-transmitting mosquitoes in the UK and Europe and increased risk of tick-borne Lyme disease due to climate change (Brown et al. 2014). Medlock and Leach (2015) conclude that further research attention needs to be attributed to future drought, vector-borne diseases and appropriate adaptation strategies.

4 Discussion and conclusions

Our findings provide further understanding of the potential effects of drought on health and well-being in the UK. In applying the source-receptor-impact framework, we show that the sources through which drought might affect human health and well-being are often similar in both the developing and developed country contexts. However, impact pathways and the nature and extent of the effects from the sources vary, so that drought-health effects were generally perceived as less

extreme, and of a different nature, to those in developing countries. 'Drought' in the UK was most often expected to negatively impact people's health and well-being if livelihoods and affordability of food are affected. Drought was also expected to negatively affect health and well-being if it contributed to diminished environmental quality and usability of both green and blue spaces. However, if drought improves environmental quality and access to recreational activities, this was expected to present positive physical and mental health outcomes. The above issues were all common precursors to mental health and well-being effects, which were strongly associated with UK drought, compared to issues such as food security, nutrition and hygiene and sanitation common in developing countries. This aligned with findings from similar developed countries like Australia. Like the international literature, our study found that potential mental health effect recipients were usually those whose livelihoods, lifestyle and recreation were most easily and extremely disrupted by drought, and included farmers, businesses and PWS and outdoor recreational users. They were hence often seen as 'at-risk receptors'. The vulnerability of, and need to protect, at-risk groups is a key research finding for drought and health in the UK. The second is the impact of drought and associated heatwaves on health and well-being of at-risk groups in a changing climate.

Our findings highlight the cross-sectoral nature of the drought-health nexus, as health effects emerge as sectors such as agriculture, business, natural environment and leisure and recreation are affected by drought conditions. Narratives link the pathways to impact exposure with the stage of the drought, and the activities people are involved in. Based on the narratives, meteorological and agricultural droughts appear to be important for those involved in farming, gardening and outdoor recreation highlighting issues for agricultural, business, environment and recreational sectors. Hydrological droughts, affecting water resources in catchments, would have differential effect on water supply (depending on catchment characteristics, resilience of infrastructure, etc.), crop irrigation and outdoor recreation. Farmers are potential early recipients of health and well-being effects, as well as PWS users and household water customers in catchments reliant on surface water flows. A socioeconomic drought would affect water supply and distribution systems to the extent that loss of livelihoods and affordability of food become real threats for many at-risk people. Disruptions to the health services would also have implications for those requiring reliable water supplies for treatment including dialysis patients. We can therefore see that there are groups of people amongst the earliest receptors of some health and well-being effects, who are hence potential 'at-risk indicators' that a drought is underway in a given sector or system. Awareness of these at-risk indicator groups is useful not only for signifying drought progression but also for implementing response mechanisms. Whilst it is difficult to distinguish these drought types as an event develops, this suggests a cross-sectoral approach is needed which examines potential pathways to health effects during drought by examining systems affected and users. This allows appropriately targeting of actions in intersectoral risk assessment and adaptation planning. This could involve an operationalisation of the source-receptor-impact framework for policy purposes—moving this beyond the theoretical framework presented in Fig. 3 towards some estimation of the nature of the linkages, including consideration of any feedback loops.

As we reflect on the narrative approach used, we make three conclusions about the use of narratives in drought research. Firstly, narratives are beneficial in highlighting the cross-sectoral nature of the health effects of drought through the way they illustrate different attitudes to drought and its impacts, different perceptions and lived experiences as well as values from the diverse voices represented. Therefore, the narratives reflect the experiences, perceptions and knowledge of selected participants showing important sectors for drought-health effects within catchments. Secondly, narratives can underscore contextual factors that may be obscured using traditional scientific approaches. As reported, these could include gardening, access to nature and water-based activities.

Some of these cultural embodiments of British life are at risk under drought conditions and have implications for health and well-being of individuals and communities as found by sociologists and geographers in earlier work in this field. Finally, although narratives do not attempt to be representative (in the sense that large surveys do), they allow exploration of the richness of lived local experiences, expectations, perceptions and knowledge about a rarely discussed threat through a plurality of voices. This plurality of voices can reveal areas of consensus to provide insight into priority areas. Similarly, narratives can highlight areas with lack of consensus or contradictory information which can be just as valuable. For example, we found no consensus around drought and its effect on the spread of vector-borne diseases, but UK literature shows an emerging causal relationship between the two particularly with regard to climate change. Hence, we recommend further quantitative and qualitative research to emphasise risk, mechanisms involved and perceptions of the threat. We do acknowledge that certain voices were hidden, e.g. children and young people (mainly due to ethics), and that future work is needed to capture their perspectives.

From the above discussions, a major outcome of this research was the consensus on the perceived exposure of at-risk groups as likely early receptors of the health and well-being impacts of drought, and the need for targeted action. There is a general expectation that droughts in a changing climate present significant threat to at-risk groups. Further action is needed in terms of risk communication and adaptation strategies to reduce vulnerabilities. Increased frequency and intensity of drought and heatwave were usually associated with prevalence of concern for at-risk groups, such as infants, children and older people. Analogies of water supply interruptions during heatwaves allowed narrative development around drought, climate change and heatwave across sectors. Similarly, problems with wildfires and dust were linked with drought and heatwaves, with narratives focused on how these were expected to unfold in a changing climate. The threat of climate change was viewed with concern and uncertainty and as requiring priority throughout all catchments. The evidence base presented here significantly addresses the gap in the literature, illustrates the value of narratives in supporting and contributing to on-going policy dialogue around future adaptation strategies for UK drought and may help frame further research on the drought-health-climate nexus.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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