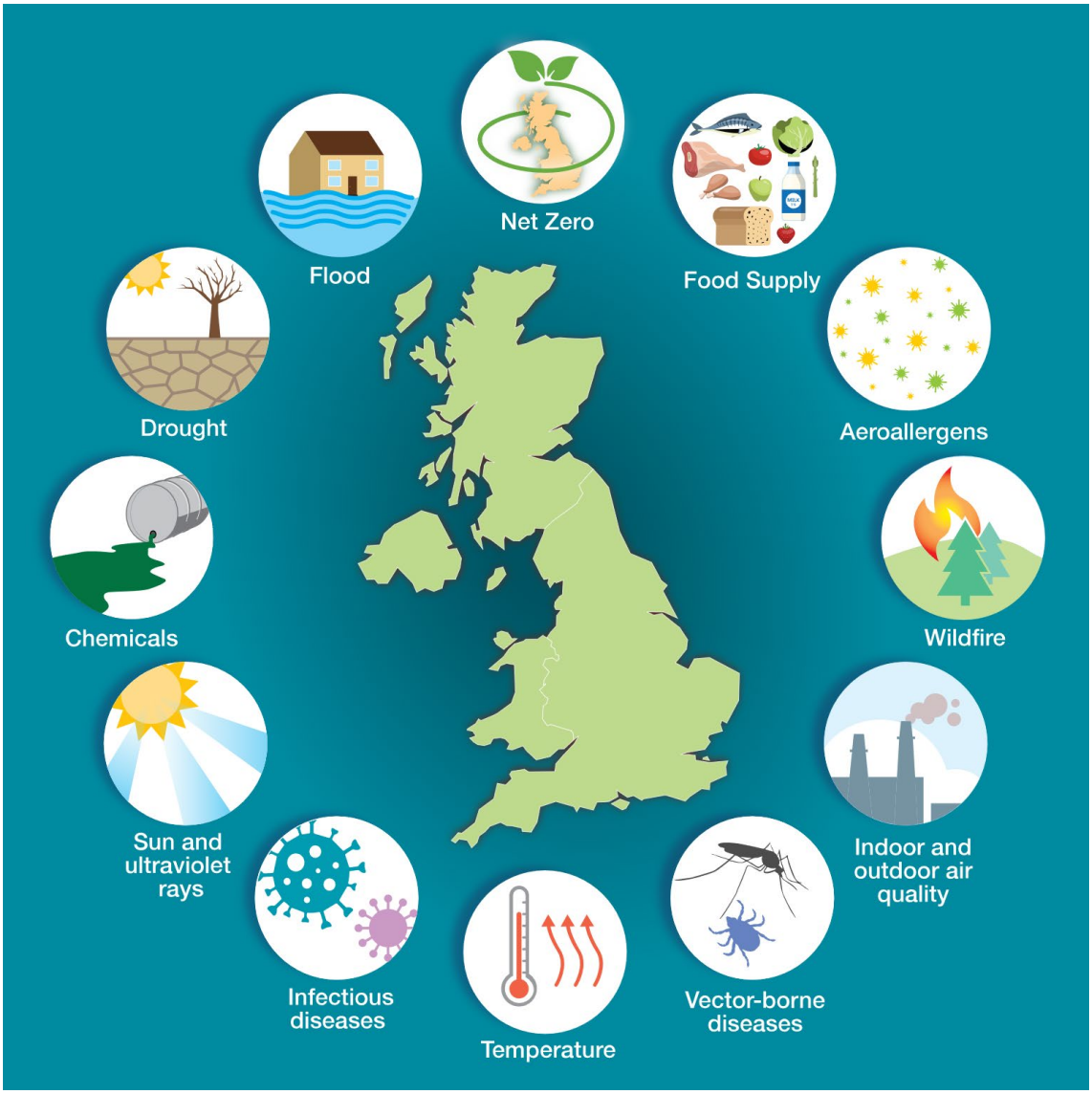
UK Health Security Agency

Health Effects of Climate Change (HECC) in the UK: 2023 report

Chapter 11. The direct and indirect effects of drought on human health in the UK



Summary

The UK is increasingly vulnerable to droughts, although they are still relatively rare occurrences. Chapter 11 presents a scoping review of the evidence on the health impacts of drought, and the future risk driven by climate change. This is the first time that a chapter on drought has been included in a 'Health Effects of Climate Change in the UK' report. The chapter was written by scientists at the UK Health Security Agency (UKHSA). The authors complement UK studies with relevant evidence from other countries in Europe, USA, Canada and Australia as the UK-specific evidence base remains limited.

In contrast to other adverse weather events such as heatwaves and flooding, droughts typically have a slow onset, and their health effects are harder to identify and are poorly understood. Droughts can impact health directly as they may affect water quality and quantity, and compromise crop yields, with implications for food supply and nutrition. Droughts also have indirect effects, for example on vector-borne diseases by influencing vector habitat, and have been linked to biodiversity loss, wildfires, increased concentrations of certain allergens and harmful mental health impacts (such as distress caused by loss of livelihood through damage to crops or livestock). As many effects are indirect, there is normally a delay in health impacts which are also often compounded by other concurrent weather-related events (such as heatwaves or wildfires). It is therefore difficult to quantitatively attribute morbidity and mortality specifically to drought.

There is limited evidence on the current UK-specific health impacts of droughts, making it difficult to estimate future risk. Evidence from other nations and climate projections indicate that drought risk is likely to increase in the UK and although not a major health risk, it should continue to be included in climate-health risk assessments as a potentially emerging risk which may be experienced concurrently with other hazards such as heatwaves and wildfires. Droughts followed by extreme rainfall may also occur more frequently, exacerbating existing health risks. To understand the risks to public health and inform work to prepare and respond to adverse weather events, it is important to assess how multiple compound events combine and interact to affect health.

During periods of drought, locally appropriate and regular communication is important to provide information to affected communities, particularly the most vulnerable. Protecting health in the context of droughts requires multi-agency efforts and coordination.

This chapter identifies 5 research gaps and priorities, including the need to:

- strengthen quantitative and qualitative research of the health impacts from drought within a UK context, including knock-on effects from ecological impacts
- improve understanding of the most vulnerable populations and development of effective interventions to protect health from drought while reducing health inequalities
- assess the impacts of drought events on food prices and shortages within the UK

- investigate the impacts of multiple extreme weather events to understand compound risks to health

UKHSA has published 'Public health impact of drought: advice for the public', which suggests ways to stay healthy during droughts, including advice on how to stay hydrated, look after your mental health, reduce respiratory problems and use water more efficiently. In April 2023, UKHSA launched the 'Adverse Weather and Health Plan (AWHP)' for England. The AWHP outlines areas where different sectors (including public, independent, voluntary, health and social care organisations and local communities) can work together to maintain and improve integrated arrangements for planning and response to deliver the best outcomes possible during adverse weather. Whilst drought is not currently included in the AWHP, there are plans to include it in the next iteration, due to be published in March 2024.

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Chapter 11. The direct and indirect effects of drought on human health in the UK

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1. Introduction

Drought has been defined as a period of abnormally dry weather characterised by a prolonged deficiency of precipitation below a certain threshold over a large area and lasting longer than a month (1). Droughts are complex phenomena; they are slow onset and gradually intensify over time, impacting many economic and environmental sectors. Several definitions of drought are used depending on the impact it has on various sectors (1), and are summarised as:

- meteorological droughts which occur in areas when dry weather dominates and are usually determined by the duration of the dry period and the degree of dryness
- hydrological droughts which are normally associated with a precipitation deficit, and occur when surface and subsurface water supply becomes low
- agricultural droughts which are associated with precipitation deficits leading to soil moisture deficits and thus negatively affects agricultural production (such as crop growth and livestock rearing)
- *s*ocioeconomic droughts which include some element of meteorological, hydrological and agricultural drought, but relates more to the supply and demand of economic goods

Quantifying and determining the impacts of drought is difficult because they are slow-onset, long-lasting events with no clearly defined beginning or end, and there are many economic, environmental and social consequences that can last for months, years or decades (2, 3). Droughts also rarely exist on their own, but often occur as compound events (for example, at the same time as heatwaves and wildfires). Droughts, heatwaves and wildfires can work in feedback loops to exacerbate the effects of each other (4). Variations in soil moisture during droughts can amplify surface temperatures and worsen the effects of heatwaves (5). Similarly, heatwaves can increase the evaporative demand in the atmosphere, leading to further drying of the upper soil layer (6). As a result of dry soil conditions coupled with warmer temperatures, there is also an increased likelihood in the occurrence of wildfires. The detrimental impacts of drought are easily overlooked and underestimated; whilst wildfires and heatwaves can occur simultaneously to drought, health impacts are often attributed to the fire or heatwave and drought is rarely considered (7).

1.1 Summary of past HECC reports

This is the first ‘Health Effects of Climate Change in the UK (HECC)’ report that explicitly considers the impacts of drought on multiple aspects of health in the UK. The first report in 2002 commented on drought presenting potential problems for water availability and supply, with a need to continue to monitor and treat drinking water supplies effectively (8). The 2002 report also commented on 2 cryptosporidiosis outbreaks during a significant drought period in the early 1990s, from the use of alternative water supplies in the north-east and the south-east coast of England. In addition, it noted that with summer droughts, different mosquito species may find

more breeding sites in riverbeds and water butts, leaving people more exposed to mosquitos and potentially the infectious diseases they may carry. The second HECC report in 2008 did not expand upon the comments within the 2002 report but emphasised that domestic water supply failure would be the most significant consequence of drought in the UK, requiring standpipes and other methods to deliver water; potential health effects would include gastrointestinal illness due to water contamination and reduced hygiene (9). The third HECC report published in 2012 covered similar topics as in 2002 and 2008, as well as exploring further the effect of drought on the emergence of infectious diseases outbreaks including Nipah virus in Malaysia, St. Louis Encephalitis virus in Florida, West Nile virus in Mississippi, Chikungunya virus in Kenya and Konzo virus (10).

1.2 Current and future risk of droughts globally and in the UK

Since the 1950s, the global frequency of concurrent heatwaves and droughts has increased and there is high confidence that this has been driven by human influence (11). During the period 1970 to 2019, there were more deaths attributed to drought globally (650,000) than any other water-related hazard (12). In the USA, droughts are the second most expensive extreme weather event, with 24 drought events causing $223.8 billion of damage during 1980 to 2016 (13). In Europe, losses from drought are estimated to be €9 billion annually, with the highest losses in Spain (€1.5 billion), Italy (€1.4 billion) and France (€1.2 billion) (14).

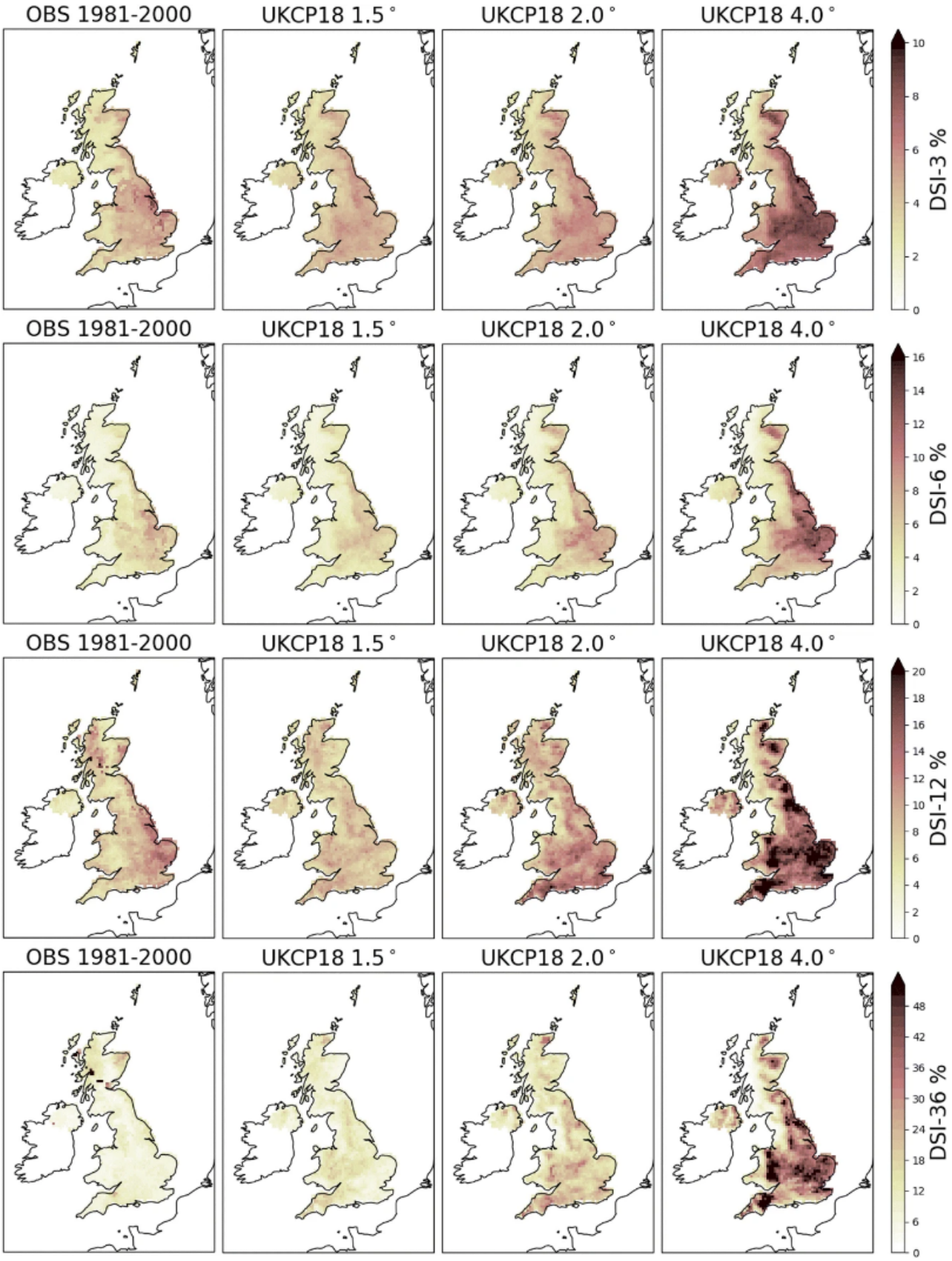
In future, the frequency of droughts will increase (11). The frequency of an agricultural and ecological drought event that occurred on average once in 10 years during 1850 to 1900 will be twice as likely if mean global temperatures increase by 1.5°C, 2.4 times more likely if temperatures rise by 2.0°C and 4.1 times more likely if temperatures increase by 4.0°C (11). It has been predicted that annual losses will rise to €9.7 billion with 1.5°C temperature increase, to €12.2 billion with 2.0°C rise and to €17.3 billon with a 3°C rise (14). The number of people facing reduced water resources for food production, domestic use and other basic needs for human wellbeing in Europe is predicted to reach 138 million people per year by 2071 to 2100, a 27-fold increase compared with 5 million people during 1981 to 2010 (15).

The UK is vulnerable to multi-season, longer duration hydrological droughts (16). However, different areas of the UK are vulnerable to different types of drought: the north-west is vulnerable to shorter, heatwave driven droughts, whilst the south-east is more vulnerable to multi-year groundwater droughts (17). Recharging of groundwater and reservoirs usually takes place during November to April, so successive dry winters prevent replenishment and cause significant water resource issues (17, 18). There have been several recent notable droughts in the UK: in 1975 to 1976, 1989 to 1992, 1995 to 1996, 2004 to 2006, 2010 to 2012 and 2018 to 2019 (17, 18). Drought was also declared during the summer of 2022, where maximum temperatures exceeded the average for much of England during June to August, and low levels of rainfall resulted in it being the fifth driest summer for England and Wales since 1836 (19). During this period, the highest ever temperature in the UK was recorded and in England the first

level 4 Heat-Health Alert and Red Extreme heat severe weather warnings were issued (20). Amber alerts were also issued for parts of Wales and southern Scotland. By the end of August, reservoir stocks were the second lowest on record since 1995, and drought was declared across most of England and Wales (19). Some parts of the UK including Devon, Cornwall and East Anglia still remained in drought as of 25 May 2023 (21). Droughts are considered as a fairly rare emergency within the UK, and there is no clear evidence that drought severity, extent or duration has increased due to climate change (22).

Whilst it is difficult to model whether the frequency of droughts will change in future based purely on prolonged and extensive low rainfall patterns, it is expected that droughts will increase due to higher temperatures drying the ground through increased evapotranspiration (22). If temperatures rise by 2°C or more, it is predicted that there will be significantly more droughts compared to the baseline period (1981 to 2000) (16). There will not be uniform changes, however, as there are likely to be reductions in drought occurrence in some areas (such as western Scotland) whilst increases in others (for example, eastern Scotland, Northern Ireland, southern England and Wales) (Figure 1) (16). Projected changes in both frequency and severity of droughts are expected to be larger in England and Wales and adaptation of water management practises within various industries are likely to be required to cope with the increased severity of drought (Figure 1) (16).

Figure 1. Maps of median values of drought impact metrics over 3 months (drought severity index [DSI]-3), 6 months (DSI-6), 12 months (DSI-12) and 36 months (DSI-36) per year for the baseline period (1981 to 2000) and the model projections (UKCP18) at 1.5°C, 2°C and 4°C of global mean warming (16)



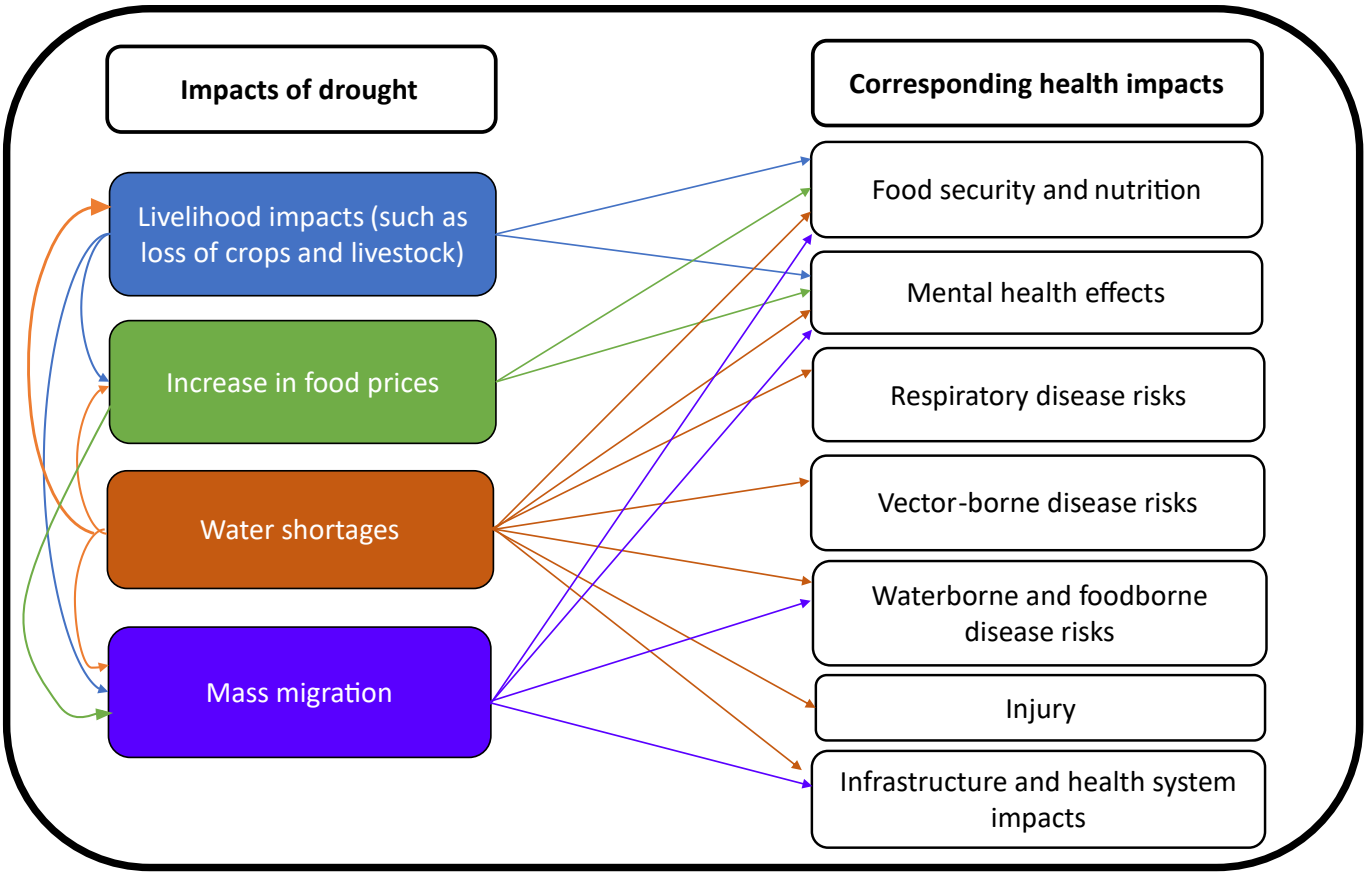
2. Health effects of drought

The health effects of drought in many countries are relatively understudied compared to other extreme weather events, such as heatwaves and flooding, as droughts generally do not tend to have immediate visible impacts. Health effects are harder to identify as they are often slow onset and drought can detrimentally impact health indirectly via multiple downstream cascading impacts (23). The harmful health impacts of drought are primarily related to mental health effects, rather than physical health; due to the indirect nature of many of the impacts, it is difficult to identify causality between mortality, morbidity and drought. The complex interplay between drought and health can be influenced by factors such as drought severity, underlying population vulnerabilities such as poverty and poor health, existing health and sanitation infrastructure and conflict (7).

Impacts arising during and following droughts can be categorised as both direct and indirect (Figure 2). Direct impacts include limited water supply, loss of crops, damage to infrastructure, and injury. Examples of indirect impacts include ecosystem changes, such as changes in breeding conditions for vectors, biodiversity loss and supply chain disruption leading to potential food insecurity and malnutrition (4). As a result of the direct and indirect impacts, drought can harmfully affect mental health, increase concentrations of certain pathogens or allergens leading to knock-on health effects, impact food security and nutrition, as well as impacting health systems delivery.

Here, we have reviewed the literature to examine the impacts of drought on health which are relevant to the UK population. A simple scoping search was conducted in PubMed using key terms such as ‘drought’, ‘health’ and ‘impacts’, for relevant articles relating to the health effects of drought. Due to the scarcity of literature specifically within the UK context, a decision was made to consider any literature from countries of similar population context or climate to the UK, though limitations for the generalisability or applicability of this evidence must be taken into account. Key reports were identified through searches on government and organisational websites (for example, World Health Organization) and through consultation with experts in this area. Snowballing of references was also carried out on the relevant articles and reports. The aim of this literature review was to map the potentially relevant health impacts of drought for the UK and identify gaps and priorities for future research or policy within a UK context.

Figure 2. Impacts of drought and corresponding health impacts (adapted from (7))



Text version of Figure 2.

Figure 2 shows the direct impacts of drought on society on the left-hand side and the potential corresponding health impacts as a result of these on the right-hand side.

The direct impacts of drought on society include livelihood impacts (such as loss of crops and livestock), increases in food prices, water shortages and mass migration. These impacts also influence each other. Livelihood impacts could lead to increases in food prices and mass migration. Similarly, increases in food prices could lead to mass migration. Water shortages can lead to livelihood impacts (such as loss of crops), increases in food prices, mass migration and civil unrest in extreme cases.

The potential negative health impacts from livelihood loss include food security and nutrition and mental health. Increases in food prices may affect food security and nutrition and mental health. Water shortages may impact food security and nutrition, mental health, vector-borne disease risk, respiratory disease risks, waterborne and foodborne disease risks, injury and infrastructure and health system impacts. Mass migration may adversely affect food security and nutrition, mental health, waterborne and foodborne disease and infrastructure and health system impacts.

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2.1 Water supply, quality and sanitation

A reduction in available water is a common feature of most droughts (7). Across England and Scotland in 2018, drought led to the reporting of 10 public water supply incidents and 76 water quality incidents to regulatory bodies (17). The 'Third Climate Change Risk Assessment (CCRA3)' states that the primary risk to health, related to water supply, will be inability to meet future demand, where usage restrictions are put in place to manage the demand on water resources (22). There is limited evidence of the impacts of interrupted water supply on health in the UK since the 1970s (22). Future projection analysis on supply-demand, has demonstrated that with no additional adaptation and scenarios of between 2°C and 4°C of warming could lead to a 1,220 million litres per day to 2,900 million litres per day deficit of water available across the UK by the end of the century, although these deficits will likely differ between areas (24). For example, by the end of the century, large parts of England, Wales and some parts of Scotland are projected to be in deficit, whilst Northern Ireland is projected to mostly be in surplus (except one water resource zone) (24). Many water companies have drought plans to prevent supply issues, but it should be noted that water quality standards put in place by the Drinking Water Inspectorate (DWI) and Drinking Water Quality Regulator must still be met. Most water companies have metered customers and charge for water on a usage basis by household. Though there are measures available to support low-income households with water charges, such charges may add pressure to households experiencing poverty to reduce their water use, with potentially negative health impacts, for example if residents have medical needs (25). Where households are not able to reduce their water use, they may instead face differential impacts on their health via the impact on their socioeconomic circumstances.

Low water levels can lead to poor water quality and reduced dilution capacity leads to higher concentrations of chemicals and nutrients, as well as lower dissolved oxygen (hypoxia), which if consumed can negatively affect health (26 to 28). For instance, summer droughts negatively affected water quality of the River Rhine at the Dutch and German border, and the impact of droughts on water quality was greater when the water quality was already poor (29). Similarly, drought conditions caused a decrease in water volume in Lake Mead, USA, which led to a deterioration in the quality of source drinking water (30). Increased concentrations of chemicals and nutrients, including nitrates, orthophosphates, chlorides and sulphates have been reported when water levels are low (28, 31), including in the UK, where drought led to greater contamination of source drinking water from dissolved organic compounds (28).

Investigations have been conducted into the relationship between drought conditions and dissolved organic carbon (DOC), showing that differing soil microbial conditions due to drought may lead to an increase in DOC production, which is harder to remove during the water treatment process (28, 32). Drinking water treatment can be heavily affected by DOC levels, leading to treatment by-products called trihalomethanes (THM), that can cause a risk to human health. In Scottish drinking water treatment plants, experiments showed that increases in temperature led to significant increases in both DOC and THMs (33). By 2050, it was predicted that if water surface temperature increased by 1.8°C, there could be a 39% increase in THMs

(33). Such increases in THMs will have significant implications for water treatment to manage the associated health risks with increasing drought conditions in the future (34).

A lack of water during periods of drought can lead to poor handwashing, resulting in diarrhoeal disease. For instance, during the drought of 1976, there was an increased prevalence of diarrhoea and vomiting in Welsh children living in areas with reduced water supply compared with areas with unaffected water supply (35). In addition, areas with the longest water supply cuts had the highest prevalence of infection; once water supply restrictions were lifted, diarrhoeal prevalence became similar across all areas (35). It is important to note, however, that socioeconomic conditions and general water management practices of affected populations will likely have changed considerably since the 1970s, meaning that these outbreaks may be less likely to occur, but important to consider. There is limited evidence of the health impacts of interruption to water supply since 1976 (22).

Increased water temperatures associated with droughts can promote the production of algae and toxic cyanobacterial blooms. Harmful algal blooms (HABs) can have both direct and indirect negative impacts on coastal resources and human health, including making water unfit for drinking (36). During 2014 in San Francisco, USA, a severe drought led to a significant increase in the abundance of toxic cyanobacteria and associated toxins; the warm water temperatures also led to the algal blooms persisting for 8 months, compared to the usual 3 to 4 months (37). Due to their toxicity, exposure to water containing HABs can pose a risk to human health, causing minor skin irritations, vomiting, diarrhoea, fever, muscle and joint pain. Indirect impacts may also include loss of recreational access to water. HABs can affect drinking water quality when present in sites such as reservoirs, leading to increased costs in water treatment, and sometimes ‘do not drink’ notices being issued. One example of this was Lake Erie, USA, where drought conditions in combination with other factors led to the suspension of tap water drinking for around 500,000 people in 2011 due to HABs (38, 39). There is also potential for HAB toxins to enter the terrestrial food chain through irrigation of crops with contaminated water and consumption of contaminated water by fish and livestock (39). The UK does carry out monitoring of cyanobacteria and toxins and has made links with increased water temperatures and higher concentrations of biotoxins present in shellfish (22). Such potential increases in abundance and duration of algal blooms during periods of drought may therefore increase these risks to human health (see Chapter 7).

In some countries, it might be possible for people to switch to a private water source during periods of drought, although the water is often poorer quality as compliance with water quality standards are not as regulated as public supplies (40). Outbreaks of waterborne diseases have been associated with private water supplies in England and Wales, including *Cryptosporidium*, *Campylobacter* and *Giardia* (41). A survey of private well owners in the USA found that more than half of participants had never tested the quality of the water, with only half of those that had tested the water had done so in the last 5 years, and not every year as recommended by the Centers for Disease Control and Prevention (CDC) (42). Private water supplies in the UK have been deemed more vulnerable to climate hazards by both affecting quantity and quality of available water, and problems were reported during the hot, dry summers in 2018 and 2019

(22). Private water supplies are particularly important in supplying multiple households in more rural or isolated communities, but they are vulnerable during drought periods to contamination from other chemicals (see Chapter 12). In England, 1% of the population get their water from private water supplies, compared with 3% of the population in Wales and Scotland (43, 44). Drought can therefore lead to inequalities with regards to water accessibility and quality within these areas, and consequentially health inequalities, particularly in groups with pre-existing susceptibility. As groups such as young children, older people and people with pre-existing health conditions are also more susceptible to the negative health impacts of heatwaves, which often occur alongside water supply disruptions, these groups are therefore likely to face compounding health impacts (45).

Hot and dry weather associated with drought can increase recreational water use, increasing exposure to pathogens. An outbreak of leptospirosis affected 5 boys in Illinois, USA after they had been swimming in a small swimming hole, with drought conditions the previous month thought to have created an environment in the pond that likely facilitated transmission (46). Similarly, 2 cases of necrotizing fasciitis were reported in Lower Austria, Austria in 2015 following swimming in separate freshwater bodies, which were thought linked to hotter- and drier-than-average conditions, that likely supported the growth of the causative agents (*Vibrio cholerae* non-O1/non-O139) detected in the water (47).

Droughts usually occur together with high temperatures, which can lead to high evaporative losses, drying up soil and plants and increasing the risk of wildfires (7). An example of this in the UK was the wildfire on Saddleworth Moor, Manchester which lasted for 24 days during the 2018 drought (17). As water cannot be absorbed as easily by extremely dry soil, there is also an increased risk of flash flooding when it eventually rains. Water quality can further deteriorate during heavy rainfall following droughts as chemicals from the ground can be washed into rivers, contributing to eutrophication, defined as the overabundance of nutrients (usually nitrogen and phosphorus) in water (1). The inundation of floodplains can also increase the risk of hypoxic water, resulting in fish and crustacean mortality (48). In addition, outbreaks of gastrointestinal infections, such as campylobacteriosis can be triggered by heavy rain following periods of drought (49).

2.2 Food security and nutrition

The impacts of drought on food security, nutrition, and therefore health, are mostly indirect, slow onset and complex, with multiple interacting factors (7). Drought can have adverse impacts on food security and nutrition locally and globally, but the effects vary hugely depending on underlying vulnerabilities, socioeconomic position of the affected communities, access to water, sanitation and health infrastructure and the overall severity of the drought (3). Drought can affect health indirectly through the interruption of ecosystems, agriculture and food supply chains, leading to reduced food security and inadequate nutrition (through either a reduction in the quantity or quality of nutrients). For instance, droughts cause long-term water shortages and extreme heat stress in crops, damaging yields and result in lower food production and

availability (50). In addition, inadequate nutrition can exacerbate underlying health conditions and increase morbidity and mortality risk within populations (7, 51). Droughts can have a particularly high impact in countries dependent upon agriculture. Over 34% of crop and livestock production loss in low-income and low-to-middle income countries is drought-related, costing US$37 billion overall (52). During the period 1961 to 2018, droughts reduced European cereal yields (wheat, barley, maize and so on) by 9% and non-cereal yields (vegetables, sugar cane, citrus, grapes and so on) by 3.8% (53). Research into the health impacts of drought in the UK is sparse, with very little specifically focussing on food and nutrition (45). Drought impacts are likely to unevenly affect UK populations, depending on their underlying vulnerabilities. Increases in food prices will have the biggest impact on those with lower incomes, the elderly, children, and young adults, introducing inequity in access to nutritional food and exacerbating health inequalities (54 to 56). With increasing intensity, frequency, and duration of extreme events and drier summers (57), it will be important to evaluate any potential future impact of drought for UK food security and nutrition.

2.2.1 Food security

Food security refers to access to sufficient, safe and nutritious food to meet dietary needs, and spans 4 main dimensions: food availability (that is, production and trade); stability of food supplies; access to food; and food utilization. Each of these dimensions can be negatively impacted directly or indirectly by drought episodes (3). The effects of drought on food security mostly affect low- and middle-income countries (LMICs), particularly in the global south, due to interactions between poverty, livelihoods and access to health, education and food systems (56, 58).

For European citizens, risks to health from the effects of drought on food and nutrition are significantly lower than other regions of the world (58). Higher income countries have diverse diets and the ability to rely on food imports from geographically scattered supply chains and countries (7). However, the ability to adapt more flexibly in the future may be required as drought episodes in other countries may affect the availability and price of imports (45).

The CCRA3 stated that “risks to UK food availability and quality from climate change impacts overseas” and “risks associated with international trade routes” require more action (59). The biggest risk (medium- to long-term) to the UK’s domestic food production comes from climate change and environmental pressures such as soil degradation, water quality and biodiversity (60), which can all be impacted by drought.

One of the main effects from drought on food security in higher income countries, such as the UK, is likely to be from food price volatility, due to international food shortages and the need to import more expensive food from elsewhere to meet demand (55). Drought-related harvest failures in 2010 led to supply shortages of cereals to international markets from Russia and Pakistan. Shortages coupled with an export ban from Russia led to an increase in the price of cereals in those countries reliant on their imports, including much of Europe and the UK. As a result, the use of food banks in the UK increased by 50% in this same year, demonstrating the

potential cascading impact of these events on food security (61, 62). Similarly, following a period of drought in the USA in 2012, the media reported increased numbers of people using food banks due to food shortages and price increases, and was considered to be one of the main drivers in food price increases in Canada (55). A more recent example from the prolonged 2018 drought in Europe caused a severe problem to EU fruit and vegetable supply from reduced crop yields and affected Northern and Central European countries the most (63). In the UK, the drought severely affected onion harvests, causing supply gaps, and led to the import of more expensive onions from New Zealand (60). It is likely that future drought impacts on food availability and imports will also interact with other factors, including events such as Brexit (see Chapter 9 for more information).

Following periods of drought there may be both within-year and multi-year impacts on food prices. For example, during the 2018 drought in the UK, reduced crop yields contributed to a considerable increase in the price of animal feed, and input costs for livestock products were as high as 20% to 25% more for some farmers (64). This led to some farmers having to sell livestock, reduce herd sizes and reduce the amount of animal products produced, which in turn led to increased prices of animal products (such as meat and milk) passed on to the consumer (64). Such cascading effects can also adversely impact the availability and price of products in following years, and if consecutive years are affected by drought, could lead to further exacerbation of these effects year on year.

2.2.2 Nutrition

Drought can contribute to malnutrition but is thought to act as a ‘trigger’, rather than a cause (7). Malnutrition is the biggest cause of health loss globally and includes both undernutrition and obesity (56). Effects on food security and increases in food prices could lead to a shift in food purchases and, therefore, dietary intake. Some healthier foods are more expensive than their unhealthier counterparts (for example, lean meat versus fattier meat) and energy dense foods (for example, more processed and those with a higher sugar and fat content) also tend to be cheaper than their less energy-dense counterparts (54, 65). With the UK being particularly dependent on imports for healthier foods such as fruit and vegetables (60), increased prices of imported food items could lead to a switch to purchases of unhealthier foods. In combination, these factors could lower the nutritional status of certain populations and increase their risk of obesity, an already growing health problem in Europe (66).

There is also some evidence to suggest that the nutritional content of food may be altered with a changing climate and growing conditions. For example, drought stress can alter the nutrient cycle and the effectiveness of fertiliser application, which in turn can affect the abundance of starch, protein, and minerals within wheat grain, although the evidence for increases and decreases in specific minerals is mixed (67 to 69). In the UK, wheat-based foods contribute significantly to the intake of B vitamins, calcium, iron, magnesium and zinc (68). Changes in the nutritional composition of foods could lead to micronutrient deficiencies within populations, such as iron deficiencies, leaving people more vulnerable to illness (7, 68). Although these factors

are important to consider, there is little to no evidence to date on the impact of drought on the nutritional quality of food consumed in the UK.

2.3 Mental health

Exposure to drought can lead to mental health issues in affected populations, with impacts including anxiety, stress, depression, and suicide in extreme cases. To date, much of the research investigating mental health impacts of drought has been conducted in Australia due to the high frequency of extreme, prolonged droughts that occur.

Many studies have focused on mental health impacts on farmers, likely due to the impact that drought has on agriculture, crop productivity and livestock losses and most suggest a negative impact of drought on farmers' mental health (70 to 76). For instance, 71.8% of farmers or farm workers reported high levels of stress due to drought (77), and farmers affected by drought had significantly higher rates of mental health problems (including distress) and lower mental health wellbeing scores compared with farmers who did not experience drought (70, 73). Drought conditions during the growing season resulted in an increase in job strain reported by farmers, primarily driven by increases in psychological job demand (74). Analysis around the impacts of the 2018 drought on the livestock and agricultural sector in the UK found that farmer wellbeing was a prominent issue and associated with financial aspects; for example, having to buy additional, price-inflated feed for livestock due to drought growing conditions leading to a feed shortage (64).

During a drought period, Australian farmers reported lower overall life satisfaction compared with the general rural community (72), with farm residents and farmers reporting significantly higher drought stress scores compared with other rural workers (78). Another study found that the distress levels of irrigators to be higher than that of farmers, with horticulturalists reporting the highest levels of distress, followed by broadacre irrigators, dairy irrigators and finally livestock irrigators (79). It is not just job strain during drought that affects the mental health of farmers, there have been reports of distress from the impact of environmental degradation and loss of hope for the future of the affected communities (80).

Mental health impacts from drought have been identified as a concern for rural communities too: these populations may have increased exposure to drought, and so are at risk from the distress or emotional consequences compared to urban communities. Several studies have reported higher levels of psychological distress in individuals living in rural areas compared with urban populations (76, 81, 82). Within rural communities, negative effects of drought have been reported for Aboriginal groups, with impacts including damaging traditional structure, exacerbating underlying grief and trauma, and aggravating socioeconomic disadvantage (83). The effects of drought on children or adolescents living in rural areas include emotional distress; worry about their family, their community and the future; feeling isolated due to feeling obligated to help their family out and having limited or no time for recreation and socialising; and feelings of loss (84, 85). In contrast, however, studies have found no link between poor mental health

and exposure to drought in women living in rural areas, suggesting that men may be more affected compared with women (86, 87). Further evidence of males being more affected than females comes from a study showing an increased suicide risk during drought in rural males aged 10 to 29 years and 30 to 49 years, but a decreased risk in rural females aged over 30 years (88). Furthermore, Australian droughts are predicted to increase in duration and intensity in future, and suicide rates among males aged 10 to 29 years and 30 to 49 years in rural areas are also predicted to increase, but a decrease for rural women aged 30 to 49 years and over 50 years is expected (89).

As a result of severe, long-term drought, people may be forcibly displaced or required to migrate from the affected area. Migration from an affected area can lead to reductions in community resources, services and support systems in the area; geographical and social isolation for those who emigrate as well as those left behind; separation from family; diminished sense of belonging; economic deprivation; and poor reception of immigrants in receiving communities (90 to 92). It is likely that underlying mental health risk factors may be higher already due to the drought events that caused displacement initially, and those with existing mental health issues are likely to be worst affected.

Other sectors, including recreational and tourism sectors may also be negatively impacted by drought. Whilst warmer, drier conditions may encourage people to spend more time outdoors, drought can have direct negative impacts on certain activities such as water sports, fishing and boating. A lack of water or change in water conditions may lead to reduced accessibility to recreational activities, with knock-on effects for both physical and mental health (45, 93). One example is in Cornwall, where a respite disability centre has use of a sailing boat to promote health and wellbeing, which cannot be used during droughts when water levels are low (45). This example demonstrates how an at-risk group could be impacted indirectly by drought conditions, with potential knock-on impacts for health (45). In addition, people working within the recreational and tourism sectors may experience mental health effects from loss of livelihood and stress: in the USA, angling business owners have reported high stress levels during drought years due to loss of business and financial concerns (93). With projected increases in the frequency and severity of droughts with climate change, this demonstrates the potential negative impacts drought may have for the recreational and tourism sectors, and therefore on the physical and mental health of both users and business owners.

2.4 Vectors and vector-borne diseases

Precipitation is vital to vector survival, particularly for mosquitoes, as they have aquatic developmental stages. Humidity is also vital to non-aquatic species such as ticks or sandflies. It may, therefore, seem counter-intuitive that drought conditions could increase mosquito abundance. A study of US wetlands, however, found that densities of certain mosquito species increased dramatically following drought events in wetlands that dried out annually, compared with those that remained wet, which was likely driven by the loss of predators allowing a rapid increase in mosquito numbers following re-wetting post-drought (94).

One vector-borne disease which is affected by drought is West Nile virus (WNV), a flavivirus transmitted by mosquitoes of the *Culex* genus. The virus is transmitted to birds via the bite of an infected mosquito; although humans and other mammals may also become infected, they are dead-end hosts (see Chapter 8). During periods of drought, rainwater is often collected in containers and stored close to houses. The storage containers not only provide breeding sites for mosquitoes but may also attract birds depending on the surrounding environment. The result is that mosquitoes and birds are brought into close contact, and there is also an increased likelihood of infected mosquitoes encountering humans. Concentrated feeding of birds on wetlands affected by drought may also enhance enzootic transmission as birds and mosquitoes can become concentrated in small spots. Studies in the USA and across Europe have identified an association between drought and WNV incidence in humans (for example, (95 to 102)). Unprecedented extreme high temperatures coupled with low rainfall in the USA during 2012 were linked to the largest outbreak of WNV across the continental USA since the introduction of the virus in 1999 (100). Counties in the USA with a high proportion of semi-permanent wetlands experiencing drought conditions had over 300% higher annual WNV incidence compared with drought-affected counties with a low proportion of semi-permanent wetlands (96). Similarly in California during 2004 to 2007, severe drought conditions were associated with increases in human WNV cases, which were likely driven by several factors including increased contact with competent avian hosts due to declines in non-competent hosts, and an increase in neglected swimming pools increasing urban mosquito breeding sites (98). Whilst there have been no local human cases of WNV acquired in the UK to date, it has been predicted that the UK could become suitable for transmission to occur in the future (see Chapter 8). It will therefore be important to consider potential mosquito nuisance biting, breeding of bird-biting mosquitoes and disease transmission when advising people on how to store water during drought conditions.

It is not only WNV outbreaks which are associated with drought, as dengue fever outbreaks have also been linked. Dengue is primarily transmitted by infected *Aedes aegypti and Aedes albopictus* mosquitoes, which are prevalent in urban areas and are able to exploit a range of containers as aquatic habitats (103). In countries where dengue is endemic, modelling studies have suggested that intense rainfall several months following a period of extreme drought provides optimum conditions for dengue outbreaks (104, 105). Similarly to dengue, Zika virus (ZIKV) is also transmitted by some *Aedes* mosquitoes, and drought has been implicated as a factor in the emergence of ZIKV in Latin America and the Caribbean during 2014 to 2016, as a severe drought was underway at the time (106). Modelling of *Ae. aegypti* distribution in Australia under future climate change scenarios suggested that a proliferation of domestic water storage tanks where larvae could develop, could result in a range expansion of *Ae. aegypti*, resulting in a risk of dengue transmission in most major cities during the summer months (107). There is a low risk of *Ae. aegypti* becoming established in the UK, so whilst the previous study focuses on *Ae. aegypti* in Australia, the findings are likely to apply to all urban mosquitoes that are able to exploit container habitats (7), and as there is a high risk of *Ae. albopictus* becoming established in the UK, there are likely to be implications for mosquito-borne disease transmission in the UK in future.

Compared with mosquitoes, little research has been conducted on the impacts of drought on ticks. In the year following drought in Illinois, USA, densities of larval *Ixodes scapularis* were significantly lower than the 8-year average at the site (108). It is likely that the drought conditions severely damage vegetation and small mammal populations, which will have resulted in increased risk of desiccation, coupled with the loss of blood hosts (108). Similarly, drought was thought to be a limiting factor on *Ixodes pacificus* populations in California, whereby tick abundance in areas affecting by drought were lower than in unaffected areas (109). Even though *I. scapularis* and *I. pacificus* are not native to the UK, it is likely that the findings of these studies will apply to native UK tick species, whereby extended periods of very hot and dry conditions associated with droughts are likely to negatively impact tick populations by reducing host-seeking activities and result in high mortality rates.

2.5 Respiratory and cardiovascular illness

Droughts are associated with poor air quality; as soils become desiccated during droughts, there is increased likelihood of dust particles in the air. During the 1930s in the USA, it is thought that thousands of people who lived in the Great Plains died from 'dust pneumonia', driven by the 'Dust Bowl' drought. More recently, residents living near a lake in Canada which had been desiccated through persistent drought reported higher prevalence of coughing, wheezing and eye and nasal irritation than residents in a control group (110). Increased dust during the California drought in 2015 caused respiratory health concerns, including allergies, asthma and other unspecified respiratory issues (111). A study estimated that in the Southwest USA under future projection scenarios, annual hospitalisations due to cardiovascular and respiratory illness as a result of exposure to fine dust exposure due to drought could increase by 59% under Representative Concentration Pathway 2.6 (RCP2.6), and 300% under RCP8.5 for adults aged 65 years and over (112). In addition, annual premature mortality of adults aged 30 years and over to fine dust exposure could increase by 24% under RCP2.6 and by 130% under RCP8.5 (112). It is not only dust, however, which can negatively affect air quality during droughts. A study in the USA found a strong link between severe droughts and air quality, with elevated surface ozone and particulate matter with aerodynamic diameters less than 2.5μm ($PM_{2.5}$), which was attributed to the combined effects of drought on decomposition, natural emissions and chemistry (113).

Several studies have investigated the effect of droughts on respiratory and cardiovascular disease hospital admissions and mortality rates. Drought events in Portugal and Spain were significantly associated with all-causes mortality rates, with higher relative risk values for daily respiratory mortality (114 to 116). Location was an important predictor, as droughts had a greater influence on daily mortality in inland areas compared with coastal regions (117). The highest mortality rates were seen in individuals over 65 years of age, likely driven by the high prevalence of chronic health conditions, reduced mobility and decreased ability to respond to environmental stressors (114, 116). There was no significant difference in cardiovascular admissions in older adults during drought periods compared to non-drought periods across western USA (118). In counties with less frequent drought, however, there was increased risk

for cardiovascular admissions and mortality compared with counties that experienced drought more frequently, possibly suggesting that as droughts become more common, populations will acclimatise to the conditions (118). In contrast, however, a study in the USA found that drought severity had no significant effect on mortality rates, although it focused on all-cause mortality, so it is possible that the effect of drought on certain types of mortality, such as respiratory- or cardiovascular-related deaths, was masked (119).

With an increased risk of wildfires during drought conditions, the risk of respiratory illness from fire smoke is also increased. Although drought-related fire smoke has been shown to have little impact on mortality, it has been demonstrated to increase respiratory stress and symptoms, particularly for those with underlying conditions (120).

2.6 Other health effects

There are several other health outcomes that have been associated with drought. Whilst the impact on health may not be less severe compared to those previously described, it is possible that there is not as much evidence, but these may be important for the UK in future.

2.6.1 Injury

During periods of drought, water availability becomes limited and large bodies of water such as rivers and lakes can dry out or have much lower levels of water than usual. Recreational swimming can increase during periods of high temperatures, with people wanting to cool down, but jumping or diving into water bodies with reduced water levels can result in injury. In Wisconsin, USA following the 1988 drought, 8 patients suffered spinal cord injuries after jumping into natural bodies of water where water levels were lower than usual (121).

2.6.2 Fungal pathogens and disease incidence

Drought changes important factors within soils and ecosystems, leading to altered microbial communities and the potential for establishment of different fungal species. Low levels of moisture within soil have been associated with the establishment of *Cryptococcus gattii,* a fungal pathogen, which can cause life-threatening diseases of the pulmonary and central nervous system (122). Traditionally only seen in tropical and subtropical regions (particularly in Australia), *C. gattii* emerged on Vancouver Island, Canada in 1999 (123), and resulted in 218 cases (5.8 cases per million persons) during 1999 to 2007 (124). It was thought that warmer, drier summers facilitated the establishment in Canada (122). To date, isolated cases have been identified in Austria, France, Germany and Greece (125). It is possible, however, that changing soil conditions could lead to future establishment within Europe (125).

Another example of a climate-sensitive fungal pathogen is *Coccidioides*, found in the soil of certain desert regions and spread by dust-borne spores, which causes coccidioidomycoses (also known as Valley fever). Airborne spores are inhaled and infection develops within the lungs, which can range from inconsequential illness resulting in lifelong immunity to reinfection,

to severe pneumonia (126). In the USA, there have been notable peaks in infections of Valley fever following drought periods (55, 120, 127). Excess cases of coccidioidomycoses have been recorded, totalling 1,467 and 2,649 in the 2 years following droughts in 2007 to 2009 and 2012 to 2015, respectively (127). Currently, the fungus is endemic to areas of the USA with a specific ecological niche. However, more infections are being recorded in areas where the fungus has not previously been considered endemic, and not associated with travel (126). This demonstrates the potential of fungal species to establish in other areas in line with changing climatic conditions.

Global drylands are expanding and predicted to continue to grow with increasing temperatures due to climate change, leading to desertification of areas of land. These drylands are characterised by low precipitation and frequent drought periods and can allow for an increase in dust-related activities. It has been shown that an increase in dust-related activities due to increasingly frequent drought periods and desertification, may alter microbial loads in the atmosphere and could increase the risk of colonisation of foreign micro-organisms into new ecosystems. Although research and knowledge of dust and sandstorm microbiota is currently limited, there is the potential for multiple opportunistic plant and human pathogens to be spread this way (128).

2.6.3 Health systems and infrastructure

There is little mention of the effects of drought on healthcare systems within much of the published research on the health effects of drought. The most likely impact of drought on healthcare systems is due to the interruption of other services, such as electricity and water supply, which could limit medicine storage and medical devices (7). In the US and Europe, thermoelectric power plants are responsible for producing 91% and 78% of the total electricity, respectively; the production of electricity is directly dependent on the availability of water for cooling (129). During periods of drought, low water availability in dams can limit the amount of energy that can be produced, which can have knock-on consequences for healthcare provision (7). Limited water supply or restrictions may also have the potential to detrimentally affect certain medical procedures that require water, for example dialysis (45).

Drought can also affect inland waterways and goods transportation, limiting supply chains (17). Lower levels of water in rivers and canals lead to shipping containers carrying reduced loads or not able to transport goods at all via this mode of transport (130). This can lead to increases in the price of goods (for example, food or raw materials for medical supplies) being carried (130), which could have a knock-on effect on food security or medical equipment.

3. Discussion

Even though there have been several notable droughts in the UK, including as recent as 2022, and even with the risk of drought increasing in future, compared with many other countries, the UK is less affected by both the direct and indirect impacts of drought. Research into the health effects of drought in the UK is sparse, with most of the relevant evidence presented in this chapter coming from studies based in Europe, the USA, Canada and Australia. Assessing the potential effects of drought on various aspects of health from similar countries can help with infrastructure and resilience planning for future potential events. Whilst the incidence of drought in the UK is likely to increase in future (16), it is difficult to predict how public health will be impacted as it is also difficult to attribute health effects directly to droughts. It is likely that health effects arising from UK droughts will be mostly indirect and span multiple overlapping economic and public sectors. Being a higher-income country, the UK can adapt its physical and financial resources, to some extent, in response to some of the effects of droughts (7). However, with a warming world and increased reliance on the global supply of resources, increased droughts in other parts of the world may also lead to health effects in the UK (45).

Individual health impacts of drought are likely to be differentially distributed across populations, depending on susceptibility, degree of exposure and the capacity to adapt. For example, impacts on food prices, food security and nutrition will most affect those on lower incomes, the elderly, children, and young adults. As has been described earlier in this chapter, harmful mental health impacts will be more prevalent in rural communities where livelihoods rely more heavily upon farming and agriculture. Respiratory and cardiovascular impacts are likely to affect the elderly and those with chronic underlying conditions. As such, these higher risk groups are likely to require additional targeting of resources when implementing or evaluating policies or interventions.

Implications for research and public health

For research, there is currently a lack of literature on the health impacts of drought on the UK in general. It is, therefore, vital to expand both quantitative and qualitative studies looking at data sources and health outcomes to gather evidence of the specific UK impacts. There is a need to conduct research focusing on the most vulnerable populations so that those most at risk are identified and appropriate action can be taken as a result. As farmers and rural communities are considered some of the most vulnerable to the impacts of drought, there should be a focus on harmful mental health impacts and improving wellbeing before, during and after droughts. It is important to investigate the international impacts of food shortages: as drought is a compound and cascading event, UK food supply and security will undoubtedly be affected by droughts occurring in other parts of the world. Research into the impacts on UK food supply is required.

During periods of drought, increased public health messaging in affected areas (for example, (131)) will be important in relation to water use and efficiency, staying hydrated and reducing

health issues. As the indirect effects of drought on public health are wide-ranging, there needs to be specific recommendations to vulnerable populations for different health implications, as it is not always the same populations at risk. For instance, persons with chronic respiratory issues may be most at risk of poor air quality, whilst farmers or rural populations may be most at risk of mental health problems (132). It is important that interventions focusing on populations most at risk will allow for service provision and support to be most effective during drought periods. It will also be important to design and make available resources and materials for public health professionals responding to health issues during and following a drought period.

Actions relating to reducing drought impacts span multiple sectors and require co-ordination between multiple organisations and departments to build resilience. One of the critical recommendations from the Global Assessment Report (GAR) Special Report on Drought is to develop a national drought resilience partnership that works to link national and local government with public, private and civil society partners (4). As there are so many health effects associated with drought, it is vital that any such partnerships also include health representatives. For example, in England, the Environment Agency has developed a drought response framework, which provides a strategic overview for drought management to minimise damage to the environment and secure essential public water supply (18). The framework discusses response to droughts, including establishment of the ‘National Drought Group’, an external stakeholder group that provides a multi-sector overview and strategic drought management. Whilst the framework does not directly relate to health, many of the actions involve managing droughts to keep water supplies resilient and reduce impacts on the environment, which can have an indirect negative effect on health.

Acronyms and abbreviations

Abbreviation	Meaning
CCRA	Climate Change Risk Assessment
DOC	dissolved organic compound
HAB	harmful algal bloom
HECC	Health Effects of Climate Change in the UK report
RCP	representative concentration pathway
THM	trihalomethanes
UKHSA	UK Health Security Agency
WNV	West Nile virus
ZIKV	Zika virus

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