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Public health impacts of drought in high-income countries: a systematic review

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Abstract

Introduction

The health effects of drought are significant and widespread, but primarily indirect. As climate change projections indicate future increases in drought events globally, it is essential that we continue to develop the evidence base on the health consequences of drought to inform future public health policy and practice (i.e. the quantification of impacts now and in the future).

Methods

A systematic review was preformed using: MEDLINE, EMBASE, PsycINFO, Maternity and Infant Care, Global Health, CINAHL and Cochrane. Articles were included in the analysis if they met the following criteria: exposure was specified as drought; outcome was a defined and measured human health outcome; a distinct link had to be made between exposure and outcome; drought was defined as a shortage or deficiency that was climate related; population studied was member countries of the Organisation for Economic Co-operation and Development (OECD) to represent HICs; reported original data; published in English from May 2012 to June 2017.

Results

10,383 citations were initially identified; 24 papers met the eligibility criteria. Additionally, seven papers not meeting the criteria were incorporated as supporting text. The majority of studies were from Australia and the USA. Five main categories of health effects were found: (i) water borne disease (ii) vector borne disease (iii) airborne, dust and respiratory related diseases (iv) mental health and wellbeing and (v) other health effects.

Conclusion

The limited evidence suggests that the mental health impacts of drought in rural and farming populations and outbreaks of West Nile Fever in places that harbour the transmitting vector represent the greatest public health concern for drought prone High-Income Countries (HICs). A range of initiatives were identified, including health services preparedness alongside targeted public health policies. Further studies are needed to address gaps in the evidence including the absence of a standardised definition and/or measure of drought exposure, and methods to measure and assess health impacts related to drought.

Introduction

Climate change is a threat to the global community. With earth's temperature projected to rise by approximately 1–6°C degrees during the 21st Century (Collins and Krinner 2013), more extreme weather patterns are expected to result in heatwaves, flooding, windstorms and drought (Easterling et al. 2000). Human related activities such as overgrazing, excessive irrigation, deforestation and soil erosion are also expected to contribute to an increase in drought (Mainguet 2012). Long periods of severe and recurring of drought have already been seen in recent years, in both high income countries such as the USA and Australia (Andreadis et al. 2005; Jonathan et al. 2015) and low income countries such as the Sudan (Elagib and Elhag 2011). Whilst there remains uncertainty around the global-scale trends of drought, projections suggest that drought events will continue to occur with increased frequency, intensity, and duration, threatening hydrological systems and water security in many regions globally (Barros et al. 2014; Trenberth et al. 2014). The 2017 UK Climate Change Risk Assessment Report identified shortages in public water supply as one of the top six inter-related climate change risks (ASC 2016) and between the years 2070–2100, the number of people faced with reduced water resources in Europe is expected to increase 27-fold, affecting up to 138 million people (Forzieri et al. 2017).

Despite these projections, drought remains a low priority on national agendas with many countries yet to adopt a National Drought Preparedness Policy (Wilhite et al. 2014). This has led to an urgent call for governments to move away from a reactive crisis management approach towards a more proactive and risk-based approach in minimising the impacts of drought (Sivakumar et al. 2011). Formulation of such policies will require coordination of multiple sectors, of which public health is a key component. Therefore, there is an urgent need to quantify and improve the understanding of the impacts of drought on human health to support the development of evidence-informed health and national drought strategies.

Despite the number of drought events that have occurred globally, the available evidence for quantifying the health impacts of drought remains limited. This is largely due to the many challenges associated with studying it, including: the definition and characterisation of drought as an exposure (Svoboda and Fuchs 2016); the many indirect pathways by which drought impacts health (Stanke et al. 2013; Vins et al. 2015); and the difference in contextual components, such as underlying population vulnerability, that may work to either exacerbate or mediate the health impacts.

An initial systematic review of available evidence for the health impacts of drought globally was published in 2012 (Stanke et al. 2013). The health effects associated with drought included: (i) nutritional effects (ii) water related disease (iii) airborne/dust related disease (iv) vector-borne disease (v) mental health (vi) other.

Upon exploration of the contextual differences that contributed to the different health outcomes identified, country income level was found to be a major determinant of the health effects observed. Drought-related impacts on nutrition and communicable disease were mostly commonly reported by studies in low and middle-income countries (LMICs) whilst reports from high-income counties (HICs),

largely focused on mental health and respiratory problems with a smaller number also reporting impacts of vector borne, water borne and injury related diseases (Stanke et al. 2013).

This study aims to address the paucity of evidence on the health impacts of drought in England by systematically reviewing the global evidence base, specifically Organisation for Economic Co-operation and Development (OECD) member states, to inform future drought management strategies and public health responses in HICs.

Methods

Data Sources and Search Strategy

This review focused on studies published on or after 1st May 2012 and before 22nd June 2017. It was designed in accordance with PRISMA guidelines (Moher et al. 2009). All studies were identified through electronic search strategies only. Electronic databases were searched for relevant published studies. The databases included were Maternity & Infant Care, Global Health, Embase, Medline and PsycINFO which were accessed via OVID as well as the databases CINAHL and the Cochrane Collection. Search strategies were individually adapted for each database. Additional peer reviewed studies that were not available on the databases searched were identified using Google Scholar. As this study aimed to map the availability of peer reviewed evidence, no grey literature was included in the review process but instead these were incorporated as supporting text.

To identify relevant exposure, the first Boolean search was done to explode (by subject heading) and map the keyword “drought”. Other words related to drought were searched as keywords only. These terms were combined using the Boolean operator “OR”. The second Boolean search was done to explode (by subject heading) and map multiple health outcomes, all of which were then combined using the Boolean operator “OR”. The first and second Boolean searches were then combined using the Boolean operator “AND”. To identify the relevant population the 3rd Boolean search was used to explode (by subject heading) and map keywords relevant to OECD countries. The OECD was chosen given the similarity in policy standards and goals with England, whilst remaining geographically and climatically diverse. These terms were combined using the Boolean operator “OR”. This search was then combined with the 1st and 2nd Boolean search using the Boolean operator “AND”. (Table 1).

Study Selection

After removal of duplicates, two reviewers independently examined article eligibility in a two-stage process. The first stage involved the initial screening of the abstract and titles of all identified studies to determine their relevance to the project. In the second stage, the full text of articles was assessed to determine whether they met the predetermined eligibility criteria. Only studies that met the eligibility criteria were included in the final systematic review. Any inter-reviewer disagreements about the inclusion of studies were resolved through discussion. Studies that did not meet the criteria but contained relevant information were incorporated as supporting text within the narrative analysis. The number of articles

included and excluded at the various stages were noted in accordance with PRISMA guidelines (Moher et al. 2009) (see Fig. 1)

Inclusion criteria	Exclusion criteria
Exposure must be specified as drought	Studies where a known drought indicator was used to measure exposure but did not make a reference to drought in their methodology
Outcome must be a defined and measured human health outcome	Studies that examined the effects of water restriction policy implemented during drought periods
A distinct link must be made between exposure and outcome	Quantitative studies that didn't have a "no-drought" comparator group
Drought must be defined as a shortage or deficiency that is climate related	
Population studied must be a country in the OECD	
Any type of study design and/or methodology,	
Must report original data (i.e. No reviews),	
Published in English from May 2012 onwards	

Included studies were critically appraised using the Critical Appraisal Skills Programme (CASP) scoring system checklists, for qualitative and cohort studies (CASP 2017) and the AXIS tool for cross sectional studies (Downes et al. 2016). Studies were given a grade of either "good", "fair" or "poor" (see Table 2). No studies were excluded because of quality; 14 studies achieved a "good" score overall, eight a "fair" score, one a "poor" score and one was not scored as it was a case study design.

Results

Results of the systematic review yielded a total of 10,383 citations. Following title and abstract review, 10,184 articles were excluded, and full text screening was undertaken on the remaining 199 articles. An additional 175 articles were excluded due to lack of original primary data as well as an absence of 'drought' indicated as the exposure. In total, 24 articles met the full inclusion criteria with nine papers included as supporting text (see Fig. 1 for a flow diagram illustrating the selection and screening process).

Of the 24 articles, four were from the USA, 16 from Australia, one from Mexico, one from Austria, one from Israel and one examined the health effects of drought in Europe. Drought characterization varied

considerably between studies: some studies used a single index of drought; others a combination of measures; others simply stated that drought had occurred during the period of the study. Additionally, some studies examined contemporary drought events whilst others studied historic events retrospectively.

Five major health related themes emerged: (i) water borne disease (ii) vector borne disease (iii) airborne, dust and respiratory related disease, (iv) mental health & wellbeing and (v) other health effects. These themes were used to structure and form the basis for the narrative synthesis. Studies that examined health outcomes related to multiple categories had their results split across categories in the analysis tables and narrative synthesis.

(i) Water Borne Disease

Necrotizing Fasciitis

The evidence for waterborne disease was very limited, consisting of only one case study. Two cases of necrotizing fasciitis were reported in Austria within one month of each other (Hirk et al. 2016). Each case had reported swimming at separate fresh water, non-European Union registered bathing sites. Both sites were previously not known to harbour the bacteria *V. cholerae.* It was hypothesised that the heatwave and period of summer drought during that period had led to optimal growing conditions for the bacteria in those environments.

(ii) Vector Borne Disease

A province in Turkey experienced outbreaks of Tularemia after a period of unusually heavy rainfall which followed a dry 17 year period. The majority of the cases occurred in areas with higher altitudes (Balci et al. 2014).

Multiple studies found drought to be associated with West Nile Fever (WNF) (Aharonson-Raz et al. 2014; Anyamba et al. 2014; Marcantonio et al. 2015). In 2011 in Texas, USA and in 2012 in the central USA, the widespread and persistent nature of drought indicated by negative Normalized Difference Vegetation Index (NDVI) values as well as high temperatures appeared to coincide with large-scale epidemics of WNF in both areas (Anyamba et al. 2014). Summer drought was also found to be a key predictor of WNF outbreaks throughout regions in Europe, Africa and Asia (Marcantonio et al. 2015). Another study reported that periods of spring drought, where precipitation was significantly lower than average, preceded epidemic states of WNF observed in Israel in both 1999/2000 and 2004/2005 (Aharonson-Raz et al. 2014) Taken together, these studies suggest that drought conditions, particularly surrounding periods of spring and summer, increase the likelihood of WNF outbreaks occurring. One study examined differences in environmental factors (wetland configuration and hydrological regime) and their association with higher incidence of WNF during periods of drought in the USA. This study found that drought-affected areas with a high proportion of semi-permanent wetland had over 300% higher annual incidence of WNF incidence than drought-affected areas with a low proportion of wetland (Skaff and

Cheruvelil 2016). This study highlights the complexities involved with assessing the relationship between weather patterns, vectors and subsequent health outcomes.

In 1915 a typhus epidemic in Mexico occurred, this was also a year characterised by drought (Rodriguez 2016). An analysis of 22 typhus epidemics between 1655 and 1918 in Mexico found them to be assocaited with drought periods where Palmer Drought Severity Index (PDSI) values, an index of meteorological drought, fell significantly below the average of all remaining years. (Burns et al. 2014)

(iii) Airborne, Dust & Respiratory Related Diseases

In the USA, hospital admission risk for respiratory disease in a population of geographically diverse elderly patients was found to be significantly reduced during periods of full drought compared with non-drought periods (Berman et al. 2017).

Respondents of a Community Assessments for Public Health Emergency Response (CASPER) health impact assessment conducted in Calfornia USA reported worsening of respiratory conditions including asthma and allergies upon perceived increased amounts of dust during the drought period (Barreau et al. 2017). An inverse association between Palmer Hydrological Drought Index (PHDI), an index of hydrological drought, and the prevalence of hayfever across the states in the United States was also reported, such that drier states had more hayfever. (Silverberg et al. 2015)

(iv) Mental Health & Wellbeing

General

Multiple studies have found drought to be associated with adverse mental health outcomes. Respondents of a health impact assessment conducted in Calfornia USA reported that the drought had a negative impact on their household's peace of mind or that a drought-related experience in the past 30 days lead to acute mental stress (Barreau et al. 2017). Some respondents also reported worsening of pre-existing mental conditions of someone in their household since the drought began (Barreau et al. 2017). Another study found that those living in drought affected rural areas were more likely to have mental health problems and have a lower average mental health wellbeing score than those living in rural areas that were not drought affected (Edwards et al. 2015).

Drought appears to have a greater effect on the mental health outcomes for rural communities in particular, with studies finding that a long period of recent cumulative unbroken drought was associated with an increase in poor mental health outcomes for people living in rural but not urban areas. (Friel et al. 2014; O'Brien et al. 2014). Of those within rural communities, farmers in particular appear to be most affected by drought and have the greatest risk of adverse mental health outcomes. Several qualitative studies explored insights and determinants of emotional distress experienced by farmers during periods of drought (50–54). Drought was listed as a major stressor by farmers in South Australia, alongside other drought-specific related stressors such as poor crop yields, unsatisfactory conditions for livestock and overwhelming workloads (Fennell et al. 2016). Farmers in Australia also described wind erosion that

occurred as a result of chronically dry conditions as having a negative impact on their emotional wellbeing (Ellis and Albrecht 2017). Another study saw that when farm viability is threatened and farmland degraded through drought or economic pressures, male farmers experience shame and an 'undoing' of masculine subjectivity that constitutes a suppression of their farming identity (Bryant and Garnham 2015). A life chart analysis of Australian farmers who had died by suicide identified drought to be an environmental factor that reflected on the pathways of the majority of suicide cases. Drought was thought to have acted as a stressor by contributing to financial difficulties of the farmers (Kunde et al. 2017). In contrast, when the concerns of wine grape growers in South Australia were examined, it was found that they thought of drought as a factor that helped to mitigate other stressful micropolitical issues of the wine industry they were facing, rather than as a source of stress itself (Bryant and Garnham 2013).

A qualitative study in Australia suggested that multiple stakeholders in rural communities, not just farmers, experience profound levels of financial and emotional stress and anxiety during periods of drought (Ng et al. 2015). Another qualitative study also reported that it was not farmers that experienced poor mental wellbeing as a result of the farming pressures of drought as they were able to adapt. Instead, drought appeared to have an impact on the mental wellbeing of those living in farming communities due to the degradation of green and natural spaces such as the rivers, parks, and home gardens (Sherval and Askew 2012).

One quantitative study in Australia found that farmers exposed to drought were more likely to experience mental health issues and have a lower wellbeing score than other rural employment sectors who had been exposed to drought (Edwards et al. 2015). Another study also found that that Australian farmers' overall life satisfaction, a measure of wellbeing, was significantly lower than that of the general rural community during a period of drought (Obrien et al. 2012). This was confirmed in another study where farmers in rural Australia were more likely to report higher levels of adverse mental health outcomes than those working in other occupations rurally (Brew et al. 2016). However, farmers also reported higher levels of drought stress and this difference in drought stress was not significantly associated with the change in mental health outcomes (Brew et al. 2016). Overall there appears to be strong evidence that farmers and rural communties in general are more likely to experience adverse mental health outcomes than other rural residents during periods of drought.

Few studies assessed the difference in impacts by gender, apart from a small number of Australian studies of farming commuities. The findings in these studies was mixed but provide some evidence that amongst farming communities of Australia, women may be more resilient to drought.. Australian women in one study acknowledged that they had a few tough years associated with drought but that they were resilient enough to manage the challenges associated with it (Harvey 2014). No association was found between exposure to drought and mental health outcomes in rural Australian women aged 45 to 61, both generally or in potentially vulnerable groups including those who were more geographically isolated, poorer, less educated or pre-exiting chronic disease or poor mental health (Powers et al. 2015). Another study found no difference in self reported health or wellbeing outcomes between Australian women exposed to adverse climate events, primarily drought, and those who weren't (Powers et al. 2012). Rural

Australian females were also found to be at decreased risk of suicide with increasing duration of drought for all age groups, whereas increased drought duration was found to be associated with increased risk of suicide in rural males aged 30–45 and 10–29 (Hanigan et al. 2012). However, another study found no difference between the levels of distress reported by male and female farmers South Australian farmers (Gunn et al. 2012).

Similarly, few studies assessed the role of age as a mediator of the relationship between drought and health outcomes. One study found that younger farmers in the 25–54 age group experienced significantly higher levels of distress than those in the 55–64 age group but not those aged 65–74 years (Gunn et al. 2012). Living in drought conditions appeared to negatively affect the wellbeing of Australian women as they aged with some reporting the impact it had on their ability to retire and coping with the symptoms of menopause by adding to depressive feelings (Rich et al. 2012). There appears to be no clear association between age and sex on the mental health outcome of drought stricken rural residents. This may be because the relationship is complex or because few studies have assessed this.

The effect of drought on psychological distress was found to be greater in people who had missed a meal compared to those who hadn't (Friel et al. 2014). This association was statistically significant for all drought exposures except that of recent long dry periods of drought. This suggests that the extent to which one's mental health is affected by drought depends on the degree to which the drought has affected their ability to sustain aspects of their livelihood.

Finally, a qualitative study discussed the potential of adverse mental health outcomes in elderly gardeners because of water restriction policies implemented during drought periods so that maintaining their residential gardens became challenging (Adams et al. 2014). The results suggest however that the gardeners were mostly resilient and found way adjust to the policy by using other water sources to maintain their gardens.

(v) Other Health Effects

In Australia, 50% of all bushfire related loss of life between 1901–2011 occurred during days when the 3 pm Fire Weather Severity Index (FFDI), an indicator of drought exceeded 100, conditions which are deemed 'Catastrophic' (Blanchi et al. 2014). This highlights the role of bushfire as a concurrent risk to drought and suggests that fires occurring during more severe periods of drought result in increased incidence of fire related mortality.

No significant differences in risk of cardiovascular admissions or mortality in an elderly population in the USA were seen between during full 'moderate,' 'severe,' 'extreme,' or 'exceptional' drought periods compared with non-drought periods (Berman et al. 2017). During periods of high-severity worsening drought, a significant increase in risk of mortality and a non-significant increase in risk of cardiovascular disease, compared with non-drought periods was found (Berman et al. 2017). There was no association seen between drought severity and risk of respiratory admissions. Risks for mortality and cardiovascular admissions during drought periods compared with non-drought periods were elevated in counties with

less frequent drought suggesting that those who weren't used to experiencing drought were more likely to experience adverse health outcomes (Berman et al. 2017).

Households during the 2015 Californian drought generally reported that it had negatively impacted the health of their household members, specifically the worsening of a chronic disease since the onset of drought with some reporting that they had sought additional medical care as a result (Barreau et al. 2017).

Discussion

Summary of the Evidence

The results of this systematic review highlight multiple health outcomes associated with drought in HICs. Most studies were conducted in either Australia or the USA and, as expected, there were no studies relating to nutrition related health effects and only one study relating to water borne disease. The results of this study strengthen the hypothesis that the risk of these health effects occurring during drought in HICs are low due to factors such as the level of social support, and resilient water and sanitation systems.

There is good evidence that suggests that impacts on the mental health of rural communities, particularly the rural farming population, is the greatest health burden during periods of drought in HICs. Rural communities are already at a disadvantage with regards to access to health services (AIHW 2017), however it has been shown that farmers are even less likely to access health services, including both primary care general practitioners and mental health professionals, than their non-farming rural counterparts (Brew et al. 2016). Targeted services are crucial to address the needs of rural populations and increase access to health services, especially during periods of drought.

Multiple respiratory health outcomes have been linked to drought; however, this review found that the available evidence was limited and conflicting. While one very comprehensive study found overall hospital respiratory admissions to be reduced during drought, these findings conflict with the larger body of evidence that suggests greater incidence of respiratory conditions during times of drought, including allergenic type conditions such as asthma, wheezing and hayfever, dust related conditions such as coughing and coccidioidomycosis as well as silo gas exposure. This inconsistency in evidence could be due to the lack of sensitivity of the hospital data, which does not capture the incidence of less severe respiratory problems (i.e. not requiring attendance/admission) or could be due to how respiratory outcomes are classified, aggregated or coded for. Additional observational studies are needed to determine the nature of the association between drought, incidence of respiratory outcomes and health system usage.

This review also identified good evidence that the vector borne disease WNV is another potential health outcome that should be of immediate cause for concern for HICs during drought periods, especially as several WNV transmitting mosquitoes can now be found in many part of Europe and the USA, and several

recent outbreaks have already occurred in these regions (ECDPC 2018; Medlock and Leach 2015). This is a particular concern, given some of the evidence emerging showing that drought conditions encourage the proliferation of vectors at remaining pooled bodies of water, whilst also increasing vector competence (Johnson and Sukhdeo 2013). As drought is predicted to become more frequent and, given the strong evidence that associates WNF outbreaks and epidemics with periods of drought, WNF outbreaks may also increase in frequency.

Epidemic typhus is another vector borne disease, spread by body lice, that also appears to be correlated with drought periods. The single study within the OECD identified in this review was carried out in Mexico, one of the only upper-middle income countries in the OECD. Whilst epidemic typhus has been limited to developing countries in recent years, policy makers in places such as Europe as well as the USA should still be alert for potential outbreaks given that body lice infestation still exists within homeless populations in these places (Raoult et al. 2001).

Although few cases of water-borne infections were identified, the evidence supports the avoidance of public swimming in non-government regulated bodies of water during periods of drought, both from an injury and water borne disease perspective.

Data linking mortality is also limited, although there appears that severe drought increases likelihood of fire related mortality, suicide death in rural working males as well as mortality in elderly populations. This evidence gap may reflect the absence of an association between drought and increased mortality, due to the protections a resilient infrastructure provides; however, it could also reflect the methodological challenges with defining and measuring the exposures and impacts of drought, and the difficulty with attributing a small number of health outcomes with a diffuse and/or distal exposure.

The existing evidence suggests a trend that communities that experience drought less frequently, may face more severe health effects than those who incur drought more often and have adapted and gained resilience (Berman et al. 2017; Friel et al. 2014). This is a similar phenomenon that has been seen in studies of temperature and heatwaves (Curriero et al. 2002). Therefore, there is heightened concern for communities and countries globally that may experience drought for the first time.

Despite the gaps, this review provides sufficient evidence to support the development of multi stakeholder National Drought Plans to streamline policy implementation efforts. A health needs assessment for drought would aid the capturing of public health impacts whilst supporting and informing the public health response. The identification of cost-effective interventions that include disease surveillance, vector population control and mental health support for affected farming communities would further increase resilience. Other potential interventions include the testing of unregulated water, public educational water safety campaigns (Baker-Austin et al. 2013) and the introduction of fire bans during drought to mitigate fire-related mortality and morbidity (Hoang et al. 2013).

Drought risk is predicted to increase in light of climate change and consideration of future scenarios will need to consider additional future risks, such as health system resilience to ensure adequate adaptive

capacity and the safe delivery of healthcare (Balbus et al. 2016; Ferenc 2016; PAHO 2017). It is also important that food health and safety standards are continuously updated and monitored to reflect the changing profile of risk associated with climate change (Kirezieva et al. 2015; Markland et al. 2017).

Conclusion

The health effects of drought in HICs identified in this study are significant, with mental health of rural and farming populations in HICs being the greatest burden during periods of drought. The risk of WNF outbreaks during drought periods is also of concern especially given the increasing geographical spread of its mosquito vector. Overall, evidence surrounding other health effects is still limited and further research is needed to explore potential associations with drought. Considering these results, policy makers in HICs globally should view the formulation and implementation of both preparedness and response strategies for drought, both as a current potential risk and a requirement for climate adaption. A crucial aspect of this process will be communicating with the wider stakeholders involved. Health policy makers in particular should ensure they plan not only for the health effects identified in this study but to consider wider health monitoring and preparedness strategies to ensure health system resilience to future risks, such as vector-transmitted infections that may become more commonplace as a result of climate change.

Abbreviations

CASP Critical Appraisal Skills Programme

COPD Chronic Obstructive Pulmonary Disease

FFDI Forest Fire Danger Index

HIC High Income Country

LMIC Low and Middle Income Country

NDVI Normalised Difference Vegetation Index

NDWI Normalised Difference Water Index

NSW New South Wales (Australia)

OECD Organisation for Economic Cooperation and Development

PDSI Palmer Drought Severity Index

PHDI Palmer Hydrological Drought Index

WMO World Meteorological Organisation

WNF West Nile Fever

WNV West Nile Virus

Declarations

Authors' Contributions

VV coordinated the study. VV and JD conducted literature searches, data extraction, review selection, quality rating and evidence grading. OL, EO, & SH contributed to the design of the study and interpretation of the results. All authors, VV, JD, OL, EO, & SH read and approved the final manuscript.

Ethical Approval

Not applicable

Consent to Participate

Not applicable

Consent to Publish

Not applicable

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Competing Interests

The authors declare that they have no competing interests.

Availability of Data & Materials

Not applicable

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Tables

Table 1
– Basic Search Strategy

EXPOSURE **Drought**
Drought* OR Desertification OR Arid* OR Rain* OR Water shortage* OR Water security
AND
OUTCOME **Any Measure of Human Health**
Human OR Health* OR Disease* OR Morbidity OR Mortality OR Death OR Disab* OR Trauma OR Hospital* OR Syndrome OR Injur* OR Diar* OR Symptom* OR Poison* OR Venom* OR Cyanide OR Infect* OR Hygien* OR Viru* OR Viral OR Fung* OR Bacteria* OR Parasit* OR Patho* OR Toxi* OR Outbreak OR Water born* OR Waterborn* OR Vector OR Trachoma OR Malaria OR Schistosomiasis OR Typhoid OR Amoebiasis OR Cholera OR Hepatitis OR Salmonellosis OR Shigellosis OR Dengue OR Onchocerciasis OR Encephalitis OR Scabies OR Impetigo OR Conjunctivitis OR Scrub Typhus OR Leptospirosis OR $Zoono* OR Mental Health OR Emotional Distress OR Wellbeing OR Wellness OR Psych* OR PTSD OR Depress* OR $Nutri* OR $Nourish* OR Famine OR Cardio* OR Respir* OR Gastro* OR Asthma* OR Cancer* OR Epigenetic*
AND
POPULATION **OECD Countries**
Australia OR Austria OR Belgium OR Canada OR Chile OR Czech Republic OR Denmark OR Estonia OR Finland OR France OR Germany OR Greece OR Hungary OR Iceland OR Ireland OR Israel OR Italy OR Japan OR Korea OR Latvia OR Luxembourg OR Mexico OR Netherlands OR New Zealand OR Norway OR Poland OR Portugal OR Slovak Republic OR Slovenia OR Spain OR Sweden OR Switzerland OR Turkey OR United Kingdom OR United States OR Countr*

Table 2
– Summary of Study Characteristics

Author	Country	Drought Period	Health Outcome	Quality Rating
Barrearu et al., 2017	USA	2017	A variety of respiratory conditions Mental Health and Wellbeing Worsening of chronic conditions	Good
Berman et al., 2017	USA	2000–2013	A variety of respiratory conditions Overall Mortality Cardiovascular Admissions	Good
Blanchi et al., 2014	Australia	1901–2011	Fire Related Mortality	Fair
Silverberg et al., 2015	USA	2007	Hay Fever	Good
Brew et al., 2016	Australia	2007–2014	Mental Health and Wellbeing	Good
Bryant & Garnham, 2013	Australia	2005	Mental Health and Wellbeing	Good
Bryant & Garnham, 2015	Australia	2005	Mental Health and Wellbeing	Fair
Edwards et al., 2015	Australia	2007	Mental Health and Wellbeing	Good
Fennell et al., 2016	Australia	2012–2013	Mental Health and Wellbeing	Good
Friel et al., 2014	Australia	2007–2008	Mental Health and Wellbeing	Good
Hanigan et al,. 2012	Australia	1970–2007	Mental Health and Wellbeing	Fair
Harvey, 2014	Australia	?	Mental Health and Wellbeing	Fair
Kunde et al., 2017	Australia	?	Mental Health and Wellbeing	Good
Ng et al., 2015	Australia	?	Mental Health and Wellbeing	Fair
O'Brien et al,. 2014	Australia	2007–2008	Mental Health and Wellbeing	Good
Powers et al., 2012	Australia	1996–2007	Mental Health and Wellbeing	Good
Powers et al., 2015	Australia	2004	Mental Health and Wellbeing	Good
Rich et al., 2012	Australia	1996–2007	Mental Health and Wellbeing	Fair
Sherval & Askew, 2012	Australia	2010	Mental Health and Wellbeing	Fair
Hirk et al., 2016	Austria	2015	Necrotizing Fasciitis	N/A

Author	Country	Drought Period	Health Outcome	Quality Rating
Burns et al., 2014	Mexico	1655–1918	Typhus	Good
Marcantonio et al., 2015	Europe	2010–2012	West Nile Fever	Fair
Aharonson-Raz et al., 2014	Israel	1997–2007	West Nile Fever	Good
Anyamba et al., 2014	USA	2012	West Nile Fever	Poor

Table 3 – Detailed Data Extraction

(3a) Water Borne Disease

Author	Study Design (Where, When, Population)	Drought Exposure (How measured)	Health Outcome (What, How Measured)	Main Results
Hirk et al., 2016	Case Report Austria 2015 *n* = 2 Case 1: 73 y/o Obese Woman, Swam in brick pond 1 day before presenting at hospital. Pond is not registered as a EU bathing site Case 2: 80 y/o Man, Swam in pond 1 day before presenting at hospital. Pond was formerly a gravel quarry and is not registered as an EU bathing site.	Stated to be a drought period The rate of precipitation in July 2015 was 20 % below average (as measured from 1981 to 2010) Austria-wide	Necrotizing Fasciitis caused by non-O1/non-O139 V. cholerae. Clinically diagnosed, Swabs and blood cultures taken.	Case 1: Left lower leg, Discharged after 73 days of hospitalisation Case 2: Left lower leg, Died after 4 months of hospitalisation Both ponds were sampled 32 and 7 days after the respective exposures of case 1 & 2. Both yielded non-O1/non-O139 V. cholerae in most-probable numbers of > 11,000 per 100 ml

(3b) Vector Borne Disease

Author	Study Design (Where, When, Population)	Drought Exposure (How measured)	Health Outcome (What, How Measured)	Main Results
Burns et al., 2014	Ecological Study Central Mexico 1655 - 1918	Tree ring reconstructed Palmer Drought Severity Index (PDSI)	22 Typhus Epidemics Reported by various historical sources	PDSI values for all 22 epidemic periods were significantly below the average of all remaining years (mean −1.16; $p<0.01$) This relationship between drought and typhus epidemics was particularly pronounced when only the reconstructed PDSI values of east-central Mexico were used (mean −1.68; $p<0.001$)
Marcantonio et al., 2015	Ecological Study Europe, Asia & Northern Africa 2010 – 2012 146 areas across 16 countries	Normalized Difference Water Index (NDWI) Data from each year and area were aggregated into nine 16-week periods. The mean for each period was then calculated. Each year was then compared to the average value for their respective time period taken from the previous decade. Anomalies were then standardised.	Incidence (cases per 100,000 inhabitants) of West Nile Fever (WNF) Compiled from weekly case reports provided by the European Centre for Disease Prevention and Control	There was significant negative correlation between spring/summer NDWI and incidence of WNF. A decrease in NDWI, so drier conditions, of 0.10 predicts an increase in incidence of approximately 47 cases per 100,000 inhabitants
Aharonson-Raz et al., 2014	Ecological Study Israel 1997 - 2007	Spring drought calculated using difference in average precipitation for that period.	Cases of Human WNV Epidemics Data taken from a prior study	Transitions from endemic to epidemic state of human WNV occurred in both 1999/2000 and 2004/2005 following periods of spring drought where average precipitation that was significantly lower than the other

				years during that period ($p<0.05$).
Anyamba et al., 2014	Cross Sectional Study USA 2012	Cumulative 3 month anomalies in Normalized difference vegetation index (NDVI) and land surface temperature (LST)	Vector borne disease outbreak occurrence data information from the WHO and the USA CDC	Unprecedented 100-year climate conditions of extreme high temperatures and lack of rainfall were linked to the 2012 epidemic of West Nile virus disease on record in Texas and the rest of the continental US.

(3c) Airborne, Dust & Respiratory Related Diseases

Author	Study Design (Where, When, Population)	Drought Exposure (How measured)	Health Outcome (What, How Measured)	Main Results
Silverberg et al., 2015	Cross Sectional Study USA 2007 n = 91,642 (>1,700 per state) Children aged 0-17	Mean annual Palmer Hydrological Drought Index (PHDI). This data was then aggregated into quartiles. A lower score indicates drier conditions.	Hay fever (HF) Self-reported that they had been told by a doctor/health professional that they had hay fever. Data provided by the National Survey of Children's Health	Residence in a state with the highest quartile mean annual PHDI was associated with decreased prevalence of HF compared with that in a state with the lowest quartile (16.8% vs 18.2%; aOR = 0.89 [95%CI: 0.81-0.98]; p = 0.02) No significant difference in HF prevalence was found between the 2nd or 3rd quartile mean annual PHDI and the lowest quartile.
Barrearu et al., 2017	Cross Sectional Study California, USA 2005 n = 392 in Tulare (185 North & 207 South) n = 179 in Mariposa	Stated in paper as occurring	A variety of respiratory conditions Self-reported via questionnaire adapted from previously used CASPERS	Households in North (59%) and South Tulare (66%) reported that outdoor dust levels had increased since the drought began. Of those reporting increased dust, 68% and 61% respectively also reported that the increased dust had caused health concerns, most commonly allergies (31% & 30%), asthma (27% & 23%), and as well as other unspecified respiratory conditions
Berman et al., 2017	Cross Sectional Study USA 2000 – 2013	Weekly drought maps available from the USA Drought Monitor that uses a combination of 5 different drought indices. These were categorised	Respiratory Admissions This included: - Pneumonia & Influenza - Acute respiratory infection	There was a significant decrease in respiratory disease admissions during full drought periods compared with non-drought periods (–1·99% [95% PI: –3·56 to –0·38])

n = 2.1M from 605 counties Beneficiaries aged 65+	according to periods of - Full drought - Non-drought ----------AND---------- - - Worsening drought (which was stratified into low and high severity which were then compared to non-drought periods). This was a subset of full drought periods where the drought conditions are the same or worse than previous day	- COPD Hospital admissions taken from FFS Medicare claims and respiratory conditions categorised according to primary discharge diagnosis codes using International Classification of Diseases (ICD-9)

(3d) Mental Health & Wellbeing

Author	Study Design (Where, When, Population)	Drought Exposure (How measured)	Health Outcome (What, How Measured)	Main Results
Bryant & Garnham, 2013	Qualitative Study SA, Australia 2005 n = 30 (10 were couples) Riverland wine grape growers Aged 25 +	Stated in paper as occurring	Concerns about the social and economic effects of the occurring drought In depth personal semi-structured interview	That drought was identified as a factor that might help mitigate the issues surrounding micro-politics of the corporate wine industry rather than be a source of stress itself. “the water is not the issue. It’s the wineries that are the issues”
Bryant & Garnham, 2015	Qualitative Study Secondary Analysis SA, Australia n = 54 Riverland wine grape growers Aged 25 + as well as rate-paying irrigators from one of the local water trusts	Stated in paper as occurring	Exploring themes around masculinity, shame and suicide and the discourses and subjective dynamics that render suicide a possibility	Male farmers experience shame and an ‘undoing’ of masculine subjectivity that constitutes a suppression of their farming identity when their farm viability is threatened, and farmland degraded through drought or economic pressures.
Ng et al., 2015	Qualitative Study NSW, Australia n = 46 Key stakeholders and service providers from rural communities aged 18 +	Stated in paper as occurring	Perceptions and experiences of flood and drought during the past 5 years and their implications for wellbeing and mental health. In depth personal semi-structured	Flood and drought had profound effects on levels of financial and emotional stress and anxiety of the communities.

			interview or focus groups	
O'Brien et al,. 2014	Cross Sectional Study Australia (2007/08) n = 5012 (4093 urban 919 rural) Urban and rural residents who responded to Wave 7 of the HILDA cohort survey who had been living in the same place for the previous 7 years Aged 15 +	Calculated using a combination of rainfall data and drought indices This data was then summarised into - Cumulative months spent in drought - The intensity of how relatively dry the drought period was - The number of times an area cycled into and out of a drought period - The number of months spent in unbroken relative dryness during the last two years of the 'Big Dry'.	Psychological distress Self reported using Kessler's 10-item measure of general psychological distress scale	Constant and recent long periods of drought were significantly associated with a 6.22% [95% CI: 1.46 – 10.98] increased distress in rural residents when compared to the zero to moderate drought category. There was no change in distress between drought categories for urban residents
Powers et al., 2012	Cross Sectional Study Australia (2004) n = 6794 (3366 EC and 3218 non-EC) Women living outside major urban centres enrolled in	Exceptional circumstance (EC) areas as determined by the national Australian government, all of which were mainly drought circumstances	3 outcomes: - General Health - Mental Health - Perceived stress Self-reported using	There was no significant association found for any health or wellbeing outcome between women living in EC areas and those who didn't.

	ALSWH cohort		domains of SF-36	
Rich et al., 2012	Qualitative Study Australia (1996 – 2007) n = 78 Women enrolled in the ALSWH	Stated in paper and by participants as occurring	Wellbeing Menopause symptom management. Free text comments	Many participants commented on how long of a period they had spent in drought. Living in drought conditions was reported to impact on the women's ability to age and retire in the way that they wanted to. It appears that living in drought has an impact on a woman's ability to cope and manage the symptoms associated with menopause and adding to depressive feelings.
Sherval & Askew, 2012	Qualitative Study VIC, Australia (2010) n = 35 Individuals representing local and regional organisations, government agencies, local councils, private business, the community and farming enterprises in the rural towns of Mildura and Donald	Stated in paper as occurring	Perception and experience of drought and how the community is impacted. Semi-structured face-to-face recorded interviews, interviews via telephone, focus groups, contribution of reports or other relevant information, or a combination of these processes.	Mildura: Many spoke with great sadness about the decline and drying of the Murray river and surrounding areas and the impact this decline has had on the well-being of the community Donald: The farm and farmer have learnt to adapt to a lack of water, but the farm family's well-being is fundamentally reliant on this connection with water in what is predominantly a dry landscape in order to maintain green space such as home gardens, community parks and nature reserves of the town.
Harvey, 2014	Qualitative Study QLD, Australia Year Unknown n = 23 Woman Aged 20+ living in remote areas for at least the last 2 years	Stated in paper as occurring	Perspectives on the meaning of health and well-being, as well as the conditions that create it. Semi-structured face to face or	Strong aspect of resilience to the impact of drought, acknowledging there had been few tough years, but that they just had to get on and manage the challenges associated with it.

			telephone interviews	
Brew et al., 2016	Cohort Study Australia 2007 - 2014 n = 1184 Farmers and non-farm workers living in rural areas from the Australian rural mental health study.	Level of drought stress Self-reported using Likert scale item rating level of worry about drought (range 1–5, low to high) during a period of drought	Mental Health Self-reported single mental health question (range 1 (poor) –5 (excellent)).	Farmers had significantly lower mental health outcomes (β = −0.16 [95% CI: −0.29, −0.02]; p<0.05) than those working in other rural occupations. Farmers also reported higher levels of drought stress (p<0.01). However, this difference in drought stress was not significantly associated with this change the mental health outcome.
Edwards et al., 2015	Cross Sectional Study Australia 2007 n = 8000 People living in agricultural areas of Australia from the 2007 RRFS study.	Self-Reported as to whether participants are experiencing drought or not	Mental Health Status 5-item Mental Health Inventory from the Medical Outcomes Study 36-item Short-Form Health Survey Obtained via computer-assisted telephone interviewing	There was a significantly higher rate of mental health problems (Scores < 52) in areas of drought than in areas without drought (13.3% vs 10.8 %; p < 0.01) Mental health wellbeing score (out of 100) is significantly lower in areas in drought than in areas without drought (72.7 vs 75.5; p < 0.001) Living in a drought effected area was estimated to significantly increases the odds of having a mental health problem compared to those in non-drought affected areas (OR = 1.26 [95% CI: 1.07 -1.49]; p = 0.007)
Friel et al., 2014	Cross Sectional Study Australia 2007/08 n = 5012 Aged 15 + Urban and rural residents	Hutchinson Drought Indices were calculated suing monthly rainfall data This data was then grouped into the following exposure categories:	Psychological Distress Self-reported using Kessler's 10-item measure of general psychological distress scale	In rural areas, people exposed to 'constant and long dry' drought reported a moderate level of distress while those living in any other category who reported little distress. The there was a significant in level of psychological distress between constant and long dry drought and all other drought exposure groups except for "constant dry" (p<0.05) In urban areas, people reported a low level of distress for all drought

	who responded to Wave 7 of the HILDA survey who had been living in the same place for the previous 7 years	- zero-to-moderate drought - very dry drought - recent long period of drought - constant drought - constant drought with a recent long period		categories, with urban dwellers exposed to 'constant and long dry' reporting the lowest level of psychological distress compared with other drought categories. However, the difference wasn't significant.
Powers et al., 2015	Cohort Study Australia (1996 – 2007) n = 5441 Women living outside major urban centres enrolled in the 1946-51 Australian Longitudinal Study on Women's Health cohort	Hutchinson drought index (HDI) was linked to the latitude and longitude of the place of participant residence	Mental Health Self-reported questionnaires using the mental health domain of the Short Form Medical Outcomes Study 36-item (SF-36)	No association was found between exposure to drought and mental health outcome both generally or in potentially vulnerable groups.
Fennell et al., 2016	Qualitative Study SA, Australia (2012 – 2013) n = 309 Farmers aged 23 - 85	Stated in paper as occurring Also reported in questionnaire as a stressor	Stress Self-reported questionnaire	Drought was listed as a dominant stressor along with other drought-specific related stressors such as poor crop yields, unsatisfactory conditions for livestock and overwhelming workloads
Kunde et al., 2017	Qualitative Study Life Chart Analysis QLD & NSW, Australia	As described to have occurred by next of kin of the farmers.	Suicide Deaths As stated by the Queensland Suicide Register and	There were 2 suicidal pathways identified: Group 1: Had a brief period of stressors with an acute suicidal process Group 2: Had chronic establish mental health issues with intermittent periods of

	Year Unknown n = 18 (8 QLD & 6 NSW) Male farmers who died by suicide Aged 23 - 77		National Coronial Information System databases	hospitalisation that was suicide related One of the important contributing environmental factors reflected also on the pathways of majority of suicide cases in both groups was drought. There were thought to have acted as a stressor by contributing to financial difficulties of the farmers. It is important to note that 94% (n = 17) of all farmers were found to have a diagnosis of mental disorder at time of death.
Hanigan et al,. 2012	Ecological Study NSW, Australia 1970 – 2007 Multiple age groups aged 10+ onwards	Hutchinson drought index (HDI) used as a continuous variable	Suicide Deaths Obtained from the Australian Causes of Death Unit Record File and coded using the International Classification of Diseases.	The was a significant increase in risk of rural male suicides aged 30 - 49 in the 3rd quartile HDI, so an increased duration of drought, compared to the 1st quarter. (15% [95% CI: 8% - 22%]; $p < 0.0001$) There was also an increased risk of rural male suicides aged 10 – 29 and a decreased risk of rural female suicides when HDI increased
Barrearu et al., 2017	Cross Sectional Study California, USA 2015 n = 392 in Tulare (185 North & 207 South) n = 179 in Mariposa	Stated in paper as occurring	Negatively affected peace of mind Drought related acute mental stress Self-reported via questionnaire adapted from previously used CASPERS	Households in each sampling frame reported that the drought had a negative impact on their household's peace of mind, most commonly in Mariposa. Households reported a drought-related experience in the past 30 days indicating acute mental stress. Households in South Tulare and Mariposa County were most likely to report that a member of the household had a mental health conditions. Of those households in South Tulare 38% reported worsening of the disease since the drought began

(3e) Other Health Effects

Author	Study Design (Where, When, Population)	Drought Exposure (How measured)	Health Outcome (What, How Measured)	Main Results
Blanchi et al., 2014	Ecological Study Australia 1901 - 2011 n = 825 (733 civilians & 92 firefighters)	Fire Weather Severity Index (FFDI) was calculated based of McArthur Forest Fire danger index meter Mark 5 was stated to be an indicator of drought	Mortality Majority of data provided by the Risk Frontiers Database. Other sources were also accessed to ensure all lives lost were accounted for.	50% of all civilian fatalities examined occurred during days when the 3pm FFDI exceeded 100, conditions which were deemed 'Catastrophic'.
Barrearu et al., 2017	Cross Sectional Study California, USA 2005 n = 392 in Tulare (185 North & 207 South) n = 179 in Mariposa	Stated in paper as occurring	- Negatively affected health - Worsening of chronic condition Self-reported via questionnaire adapted from previously used CASPERS	Households in each sampling frame reported that the drought had negatively affected the health of a household member, most commonly in South Tulare. Households in South Tulare were most likely to report worsening of a chronic disease since the drought began. Of these, 20% reported that they had sought additional medical care

Berman et al., 2017	Cross Sectional Study USA 2000 – 2013 n = 5.9M from 614 counties Beneficiaries aged 65+	Weekly drought maps available from the USA Drought Monitor that uses a combination of 5 different drought indices. These were categorised according to periods of - Full drought - Non-drought --------AND-------- - Worsening drought (which was stratified into non-drought, low and high severity)	Mortality Cardiovascular admissions This included: - Rheumatic fever - Hypertensive disease - Pulmonary circulation disease - Cerebrovascular disease - Diseases of arteries, arterioles, and capillaries - Diseases of veins lymphatics - Other heart disease Hospital admissions taken from FFS Medicare claims and cardiovascular conditions categorised according to primary discharge diagnosis codes using International Classification of Diseases (ICD-9) Mortality data from death certificate counts which provide no underlying causes.	Worsening drought periods of high-severity showed a significant increase in mortality risk when compared to non-drought periods (1·55% [95% PI: 0·17 - 2·95]). Cardiovascular admissions did not differ significantly during either full drought or worsening drought periods. A one-fold increase in the ratio of a county's non-drought period days to full drought period days increased mortality risk during low-severity worsening drought periods by 0·31% [95% PI 0·12–0·51] and high-severity worsening drought periods by 0·76% [95% PI: 0·33–1·19] A one-fold increase in the ratio of a county's non-drought period days to full drought period days increased cardiovascular admissions risk during low-severity worsening drought periods by 0·72%, [95% PI: 0·15–1·30] and high-severity worsening drought periods by 1·32% [95% PI: 0·45–2·21] Counties where less than 20% of days classified as drought periods (314 counties), had a significant 4·4% increased risk of mortality and a 9·3% increased risk of cardiovascular admissions during high-severity worsening drought periods compared with non-drought period

Figures

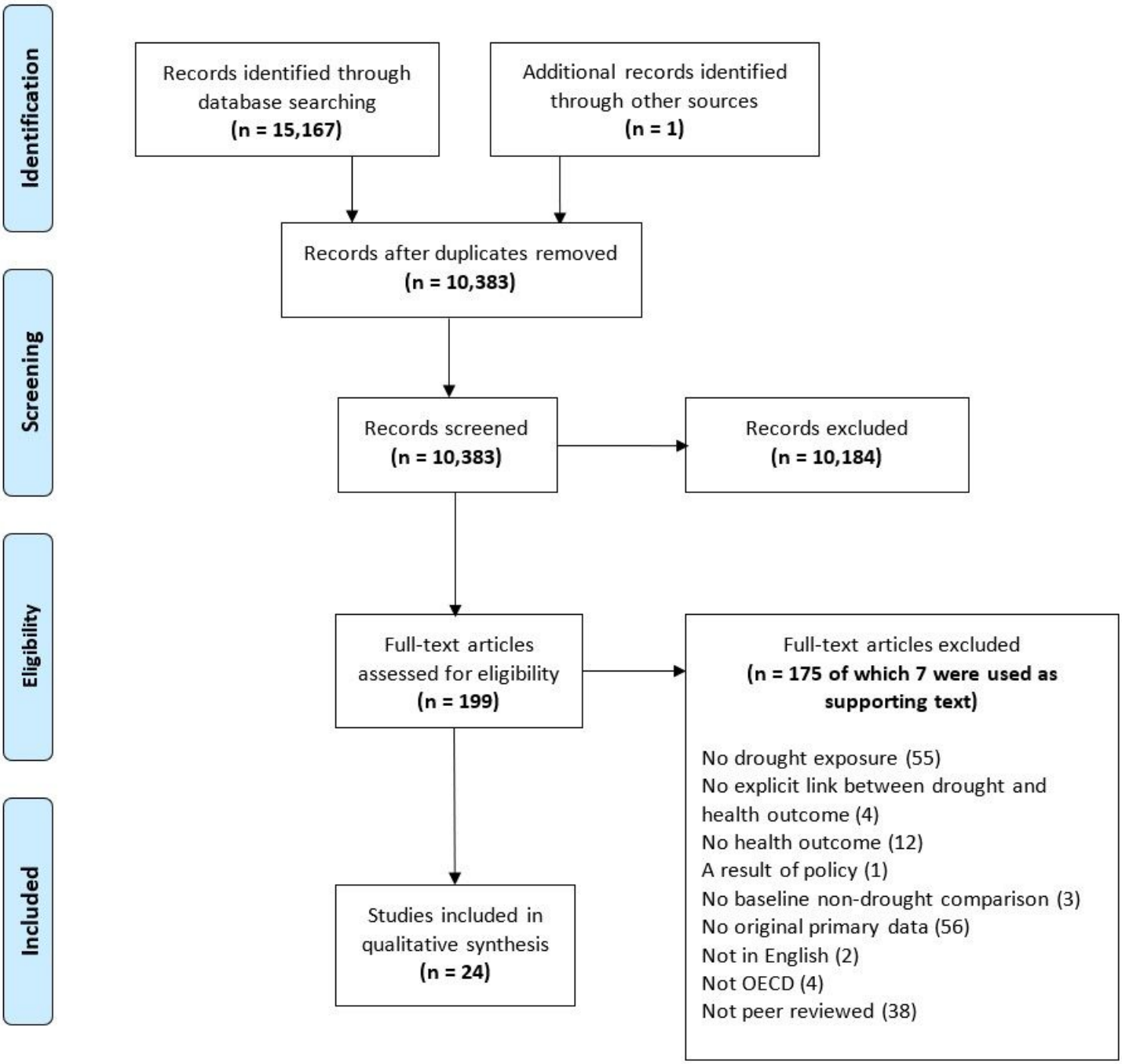

Figure 1

PRISMA Flow Diagram