Beyond reasonable drought: hotspots reveal a link between the 'Big Dry' and cryptosporidiosis in Australia's Murray Darling Basin

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ABSTRACT

There is little evidence on how the health impacts of drought vary spatially and temporally. With a focus on waterborne cryptosporidiosis, we identify spatio-temporal hotspots and by using interrupted time series analysis, examine the impact of Australia's Big Dry (2001–2009) in these disease clusters in the Murray Darling Drainage Basin. Analyses revealed a statistically significant hotspot in the north of the Australian Capital Territory (ACT) and a hotspot in the north-eastern end of the basin in Queensland. After controlling for long-term trend and seasonality in cryptosporidiosis, interrupted time series analysis of reported cases in these hotspots indicated a statistically significant link with the Big Dry. In both areas, the end of the Big Dry was associated with a lower risk of reported cryptosporidiosis; in the ACT, the estimated relative risk (RR) was 0.16 (95% confidence interval: 0.07; 0.33), and in Queensland the RR was 0.42 (95% confidence interval: 0.19; 0.42). Although these data do not establish a causal association, this research highlights the potential for drought-related health risks.

Key words | climate, cryptosporidiosis, drought, spatial, temporal

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INTRODUCTION

Spatial patterns are a fundamental component of many models of disease spread (Richardson *et al.* 2013). Infectious disease outbreaks are frequently triggered by variations in environmental conditions that favour transmission (Colwell 1996; Epstein 2001). The linkages between human and natural systems and how this may affect the spread of infections that are influenced by environmental factors has historically focused on vector-borne diseases, influenza and cholera (Morris *et al.* 2014; Parham *et al.* 2015; Charu *et al.* 2017). Despite indications that many other localised infectious disease outbreaks are synchronised by environmental factors, fundamental knowledge on how spatial context and environmental extremes can affect the spread of these diseases is lacking (Altizer *et al.* 2013, but see Paull *et al.* 2017).

As weather extremes become more frequent, the limited insight on the relationship between prolonged drought and infectious disease is particularly apparent (Levy *et al.* 2016), even though drought-related risks to health are recognised as an important impact of climate change (Yusa *et al.* 2015). In addition to knowledge of the drivers of drought (Dijk *et al.* 2013), future adaptation to climate change requires insights into the potential health impacts.

Over 60% of water-related disease outbreaks worldwide from 2011 to 2016 were caused by the parasite *Cryptosporidium* spp. (Efstratiou *et al.* 2017). Australia reports the second highest rate of *Cryptosporidium* illness in humans across developed nations (Lal *et al.* 2015a) with high rates in remote areas (Lal *et al.* 2015b). Cryptosporidiosis is also positively associated with the positive phase of the Indian Ocean Dipole, a global climate phenomenon that influences the spread of human infectious diseases, suggestive of drought-related infectious disease impacts (Lal *et al.* 2017).

South Eastern Australia has experienced some of the longest droughts to have impacted the continent to date (Verdon-Kidd & Kiem 2009). In the current study, we tested the hypothesis that clusters of human disease in space and time can signal associations with environmental extremes. First, we detected hotspots of reported cryptosporidiosis in the country's largest river system, the Murray Darling Basin, and then using an interrupted time series (ITS) analysis in these areas, we examined the relationship of reported disease with Australia's Big Dry, which spanned 2001–2009 in the country's largest river system, the Murray Darling Basin. ITS regression is typically used to evaluate interventions at a 'population level over a clearly defined time period and that target population-level health outcomes' (Lopez Bernal et al. 2016). Given the drying trend over much of Eastern Australia (Supplementary material, Figure S1, available with the online version of this paper), we hypothesised that in areas with hotspots of cryptosporidiosis, there would be a significant association of reported disease with the Big Dry.

METHODS

Data sources

All cases of cryptosporidiosis confirmed by laboratory diagnosis and reported from January 2001 to December 2012 to the National Notifiable Diseases Surveillance System (NNDSS) in the Murray Darling Draining Basin were used. The NNDSS is managed by the Australian Government Department of Health and is overseen by the Communicable Diseases Network Australia (http://www.health.gov.au/cdna). Case data obtained included date of reporting, state and postcode of residence. Ethical approval for the study was obtained from the Australian National University and the Australian Capital Territory (ACT) Department of Health prior to data release.

Statistical methods

Hotspot analysis

In this hotspot analysis all individual records of reported cryptosporidiosis over the time period 2001–2012 were imported into ArcGIS Pro 1.1. These data were analysed for correlations across space and time to identify locations where cryptosporidiosis occurred in close spatial and temporal proximity within the Murray Darling Drainage Basin using the Emerging Hot Spot Analysis tool that uses the Getis–Ord G(i) statistic (Getis & Ord 1992). The analysis yielded Getis-Ord Gi* statistic p-values and z-scores measuring the significance and intensity of hot and cold spots (Getis & Ord 1992). Next, these hot and cold spot trends were evaluated using the Mann–Kendall trend test, 'which measures the significance and direction of the temporal trend in the data' (Sadler et al. 2017) and categorises each study area location. In this study, only hotspots that were 'intensifying' or 'persistent' were mapped and used in the time series analysis. Intensifying hotspots were defined as a location that has been a statistically significant hotspot for 90% of the time step intervals, including the final time step and the intensity of clustering of high counts in each time step is increasing overall and that increase is statistically significant. 'Persistent' hotspots were locations that had been a statistically significant hotspot for 90% of the time step intervals with no discernible trend indicating an increase or decrease in the intensity of clustering over time. Hotspot analysis was carried out (ESRI 2011).

Interrupted time series analysis

Using the year and month of diagnosis for all relevant cases of cryptosporidiosis (Figure 1), time series of reported disease were prepared. Using the Australian Bureau of Meteorology official categorising of drought ending 31st October 2009, and allowing for a few months' lag for the effects to wear off, the drought period was categorised as during drought for all years up to and including 2009. 2010 onwards was categorised as 'after drought'. As ITS (Lopez Bernal et al. 2016) works best with long time series, routine surveillance data are often most appropriate. Following the published tutorial for such analyses (Lopez Bernal et al. 2016), a Poisson regression model with the outcome as reported cryptosporidiosis counts was used. The total population was included as an offset variable to convert the outcome into a rate. Models were adjusted for seasonal variation using a harmonic term with two sin and cosine pairs and the length of the period (12 months). Long-term
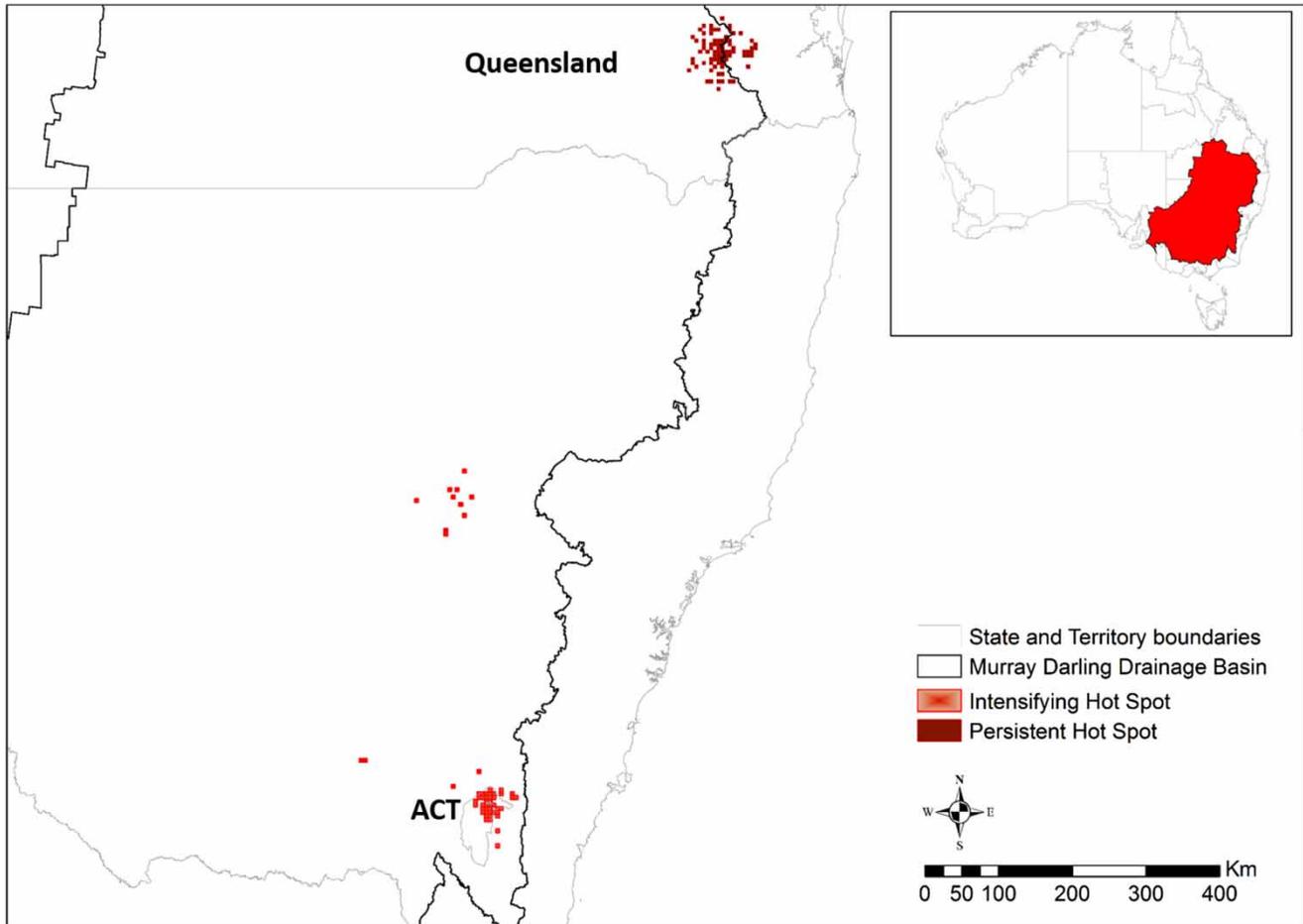
Figure 1 | Intensifying and persistent hotspots of reported cryptosporidiosis from 2001 to 2012 in the Murray Darling Drainage Basin (inset).

trend and an indicator variable to signal the end of the Big Dry were included. Autocorrelation was assessed by examining the plot of residuals and the partial autocorrelation function.

RESULTS

Figure 1 shows an intensifying hotspot in the ACT and a persistent hotspot in Queensland. A smaller scattered persistent hotspot is noted in New South Wales. Of the 2,048 cases in the Murray Darling Drainage Basin from 2001 to 2012, 385 cases occurred in the ACT cluster and 527 occurred in the Queensland cluster. In the ACT cluster, a significant decrease in the estimated risk of reported cryptosporidiosis was observed after the Big Dry, relative to the risk estimated over the

whole period (RR 0.160, 95% confidence interval (CI) 0.076, 0.335). In the Queensland cluster, a lower risk was observed (RR 0.425, 95% CI 0.196, 0.920).

DISCUSSION AND CONCLUSION

Clean water is essential for good health. An intensifying hotspot of reported cryptosporidiosis was detected in the ACT and north of the ACT, with an additional persistent cluster towards the north-eastern end of the basin in Queensland. ITS analysis of cases in these clusters showed that the end of the Big Dry was associated with a lower risk of reported illness. Modelling the relationships between the weather and health across multiple sites and seasons can inform effective and timely adaptation to prolonged drought expected in the future.

A strength of this study is the availability of long-term routine data which allowed the application of an ITS analysis. During this time period, there were no known changes in reporting of laboratory confirmed cryptosporidiosis or abrupt changes in testing practices that could bias results. One of the limitations of using such disease surveillance data is that it only captures the proportion of patients that present to health services as it is based on a disease definition that requires laboratory confirmation. It is possible that the geographic differences in the rates of reported disease may not provide an accurate picture of community burden of infectious disease (Wheeler *et al.* 1999) or the most vulnerable populations (Rowe & Cowie 2016). The main advantage of using ITS approaches is that they are typically unaffected by confounding variables which remain fairly constant, such as population distribution or socioeconomic status, as these only change relatively slowly over time and are normally taken into account when modelling the underlying long-term trend. The use of the quasi-experimental ITS design allowed us to consider time-varying confounders like seasonality and a longer-term extreme weather event.

Although our data cannot demonstrate a causal relationship between environmental extremes and disease transmission, the association of reported cryptosporidiosis with drought conditions is consistent with its predominantly waterborne route of spread. Droughts can reduce river volume and flow, potentially increasing the concentration of effluent-derived pathogens, due to reduced dilution (Senhorst & Zwolsman 2005). Deterioration in water quality following extended dry periods can also result in increases in waterborne disease (IPCC 2007). While spatio-temporal hotspots may partly be due to non-compliance of drinking water quality standards, the consistent relationship with the end of the Big Dry suggests the role of environmental transmission. This premise is supported by analyses showing the relationship of cryptosporidiosis to indices of climate variability in Australia (Lal *et al.* 2017) and elsewhere (Lal *et al.* 2013).

Our results suggest that catchment interventions appropriate to delivering safe water need to be location- and season-specific. For example, water quality is likely to show a strong response to rainfall in catchments with recent land-cover change. In such areas, environmental

and public health measures such as source protection and water treatment processes may need to be ramped up in preparation for rainfall extremes. Coordinated management of water resources at the catchment scale is well-established. Such planning fosters the achievement of many water quality objectives. In this context, we should directly incorporate human illness reduction into the assessment of water quality.

Rates of reported cryptosporidiosis are highest in rural and remote areas (Lal *et al.* 2015a), communities that are typically not a focus for water infrastructure improvements in response to drought (Waddington 2016). The focus is on maintaining and adapting water supply in urban areas such as metropolitan Melbourne (Grant *et al.* 2013; Low *et al.* 2015) and South East Queensland (Head 2014). However, rural communities on which the physical impacts of drought do not appear to have been studied (Dijk *et al.* 2013) may be the most vulnerable. Over the coming century, extended dry periods across the globe are expected (Dai 2013). In addition to the increasing evidence of the impacts of heavy rainfall on waterborne disease (Levy *et al.* 2016; Chhetri *et al.* 2017), it is important to examine the current impact of prolonged droughts on public health to inform future predictions and aid the most vulnerable (IPCC 2007).

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