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# Google Trends indicators to inform water planning and drought management

R. L. Wilby[1] | C. Murphy[2] | P. O'Connor[2] | J. J. Thompson[1] | T. Matthews[3]

[1]Geography and Environment, Loughborough University, Loughborough, UK

[2]Irish Climate Analysis and Research UnitS (ICARUS), Maynooth University, Maynooth, Ireland

[3]School of Geography, King's College London, London, UK

**Correspondence**
R. L. Wilby, Geography and Environment, Loughborough University, Loughborough LE11 3TU, UK.
Email: r.l.wilby@lboro.ac.uk

**Abstract**

Indicators are important tools for tracking the socio-environmental impacts of droughts and building resilience to climate change. We begin with an overview of metrics used for water planning and drought management, with particular emphasis on the UK. We explain how considerations of cost, immediacy, access, consistency, relevance, reliability and others denote the suitability of information for developing new indicators. We then demonstrate the potential of Google Trends (GT) online search data as drought indicators for England and Ireland. We show that search terms such as 'drought', 'water butt' and 'hosepipe ban' correlate significantly with conventional hydroclimatic data as well as with newspaper reports of various drought impacts during the period 2011–2022. GT data also show evidence of rising interest in water saving technologies, especially for outdoor water use. Meanwhile, online searches for 'Defra' and 'Environment Agency' have declined and are more often associated with flood episodes than droughts. Interest in water companies in England is more likely around hosepipe bans than water leakage (although this varies by company). We discuss the implications of these findings for targeting information campaigns, plus prospects for monitoring drought impacts and public sentiment in near real-time.

**KEYWORDS**

drought, England, Google Trends, indicator, Ireland, newspapers

## 1 | INTRODUCTION

*To measure is to manage*—a general principle that is widely adopted by statutory and non-statutory bodies alike to improve standards, services and safety. For example, schools are graded on the basis of the quality of education provided, the behaviour, attitudes and personal development of pupils, among other criteria. Hospital quality indicators include the numbers of beds and types of service available, and nurse-to-patient staffing ratios. Railway companies are judged according to their records on safety and punctuality.

Indicators are also employed extensively to support water management. For instance, many metrics standardise the long-term behaviour of primary water balance terms such as the amount of rainfall, soil moisture, groundwater or river flow (e.g., World Meteorological Organization (WMO) and Global Water Partnership (GWP), 2016). Others are

used to detect changes in catchment and regional scale hydrology, such as marked reductions in rainfall-runoff ratios following protracted droughts (e.g., Fowler et al., 2022). Metrics may also reveal changes in the timing, frequency, duration and severity of extreme hydroclimatic events that impact water supply and demand (e.g., Mehran et al., 2015) or ecosystems (e.g., Slette et al., 2019). Indicators can measure levels of service provided by public water supply systems in near real-time or under various planning scenarios, including climate change (e.g., Ekström et al., 2018). They can also define thresholds for action or impacts on society, the environment and economy (e.g., Bachmair, Stahl, et al., 2016; Bachmair, Svensson, et al., 2016). Metrics of past drought impacts can be discerned from incidents logged by agencies (e.g., Turner et al., 2021), newspapers archives (Dayrell et al., 2022; Murphy et al., 2017, 2020; Noone et al., 2017; van der Schrier et al., 2021), documentary sources (Brázdil et al., 2018) and social media (Antwi et al., 2022).

From these examples, it is evident that indicators are versatile tools for evaluating trends in drought (1) risk factors (hazards, vulnerability and exposure); (2) impacts (across various socioeconomic sectors and administrative units); (3) management and adaptation actions (as resource inputs and resilience outcomes) (ADAS, 2021). When developing new indicators, it is helpful to keep in mind some desirable properties (Table 1). Ideally, underpinning data are benchmarked to enable consistent comparisons over time and space. Climate risk or resilience indicators should be sensitive to primary hydro-meteorological variables such as temperature, rainfall, solar radiation, atmospheric humidity and wind speed. The link should be direct and physically sensible, without intermediate or confounding factors. Data should be freely available, routinely and quickly updated, plus economically feasible to sustain over decades. Long-term, quality assured and homogeneous indicator series are needed to discern emergent trends within (often) 'noisy' datasets. Finally, indicators should be interpretable by decision-makers and planners, as well as resonate with public interest. By satisfying these conditions, there is scope for the publication of indicators that can track changes in drought impacts and awareness over time, as well as offer useful insights for their management.

The indicators of the UK 25 Year Environment Plan are framed in a similar way. The Defra (2020) *Outcome Indicator Framework* has 66 metrics covering 10 main themes. These span air and water quality, natural resources, resilience, natural beauty, biosecurity, resource use and international dimensions. The resilience theme has three indicators, including for example *F3 Disruption or unwanted impacts caused by drought*. This is about *reducing the risks of harm from natural hazards* and falls under the headline of *resilience to natural hazards*.[1] The Supply Demand Balance Index assesses how the water available for supply relative to forecast dry year demands compares with what is set out in a water company's Water Resources Management Plan (Environment Agency, 2022). Water companies also have to provide related information about per capita consumption, outages and leakage rates each year.

**TABLE 1** Desirable properties of climate risk and resilience indicators. Informed by: DETR (1999) and Ekström et al. (2018).

| Property | Explanation |
|---|---|
| Benchmarked | Changes in the indicator are always compared with the same reference case, such as a baseline reporting period of 1961–1990 |
| Sensitive to climate | Variations in the indicator are associated with physically plausible climate drivers, such as between air and river water temperatures |
| Relevant to decisions | The indicator describes conditions that are relevant to planners, such as changes in per capita water consumption over time |
| Based on long series | Long series are helpful for distinguishing between short-term variations and long-term trends, as with the NHMP Outflow Series |
| Based on open data | Data used to develop and update indicators are openly and freely available, such as those from the UKCEH Water Resources Portal |
| Based on reliable data | Data used to support the indicator are quality assured with good meta data, such as groundwater levels from the British Geological Survey |
| Readily updated | Data underpinning the indicator are routinely updated with limited latency, such as HadUKP which is published within just a few days |
| Affordable to maintain | Costs are low/economically justified for long-term data collection and reporting, such as for routine water resource monitoring and outlooks |
| Few confounding factors | Variations in the indicator are driven primarily by climatic factors, such as heightened demand for irrigation during periods of low rainfall |
| Public resonance | Variations and trends in the indicator raise awareness or chime with public concerns, such as around water distribution leakage rates |

Other outcome indicators in the Defra (2020) framework cover aspects of freshwater and environmental quality but none of them explicitly refer to 'drought'. Nonetheless, drought was mentioned by 13 out of the 61 risks and opportunities in the third UK Climate Change Risk Assessment (CCRA3) (Table 2). The majority of these have a UK urgency score of 'More action needed'. This means that *new, stronger or different Government action, whether policies, implementation activities or enabling environment for adaptation, over and above those already planned, are beneficial in the next 5 years to reduce climate risks or take advantage of opportunities* (Climate Change Committee, 2021a, p. 9).

The UK Climate Change Committee (2021b) used 49 indicators to report progress in adapting to climate change to government. Eight of these indicators were drought sensitive or drought related, namely: (1) condition of freshwater Sites of Special Scientific Interest in England; (2) status classifications of surface water bodies in England under the Water Framework Directive; (3) water temperature anomalies in Southern and Northern England (Figure 1); (4) weighted average water consumption per capita for households in England 2005–20 and forecast to 2044–45; (5) proportion of properties with water meters from 1999–00 to 2019–20; (6) mid-century supply–demand balance for UK Water Resource Regions; (7) late-century supply–demand balance for UK Water Resource Regions; (8) total leakage for all water companies from 2000–01 to 2019–20 against future commitments. Supporting analyses by ADAS (2019, 2021) confirm that the underpinning evidence base requires strengthening for many of these risks.

CCRA3 refers to the National Framework for Water Resources because it sets out steps to better understand and prepare for water needs to 2050 (Environment Agency, 2020). These will require information about the incidence of rota cuts and standpipes; amounts of water abstraction; per capita water usage; leakage rates; use of drought permits and

**TABLE 2** Drought-related climate risks and opportunities identified by the CCRA3. Urgency is coded as: More action needed (red) or Further investigation (yellow). Adapted from: Climate Change Committee (2021c).

| Indicator | Link to drought |
|---|---|
| N6 Agricultural and forestry productivity | Decreased yields |
| N11 Freshwater species and habitats | Loss of habitats, reduced species abundance |
| N18 Landscape character | Changes in woodland, downland communities |
| I6 Hydroelectric generation | Reduced hydropower output and revenues |
| I8 Public water supplies | Reduced water availability |
| H1 Health and wellbeing | Wildfire and air pollution |
| H5 Building fabric | Shrink-swell of soils and subsidence |
| H10 Health | Public water supply interruptions |
| H11 Cultural heritage | Damaged buildings, archaeological sites, parks |
| H13 Delivery of education and prison services | Overheating of buildings |
| B3 Business production processes | Interruptions to water supplies |
| B6 Disruption to business supply chains and distribution networks | Insurance pay outs linked to drought indices |
| ID1 UK food availability, safety and quality | Decreased yields |

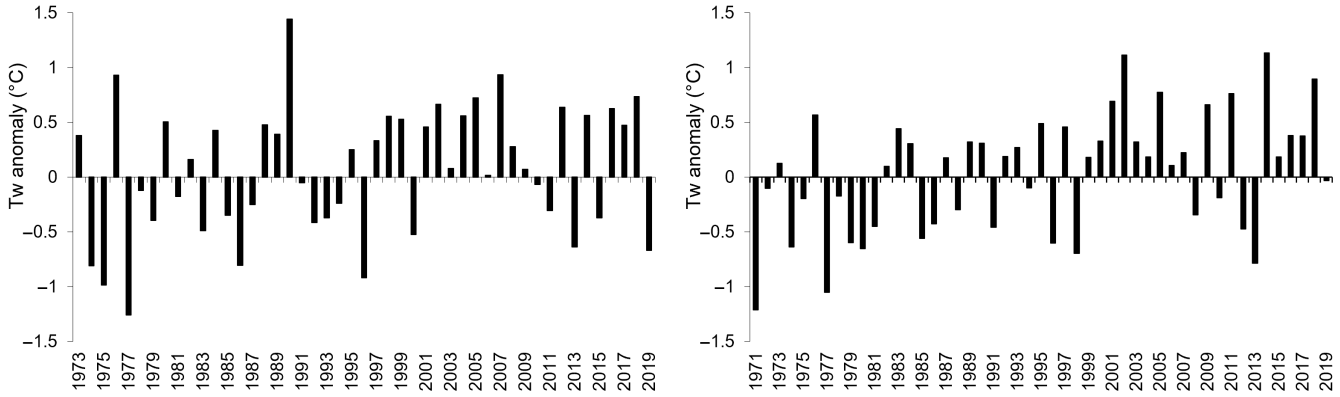


**FIGURE 1** Water temperature (Tw) anomaly index for Northern (left) and Southern (right) England showing annual variance from the long-term mean. Sources: Climate Change Committee (2021c) and Wilby and Johnson (2020).

orders; increased water supplies; and water transfers. Others have developed indicators of physical climate risks to the UK, including the proportion of time under severe hydrological drought (Arnell et al., 2021) based on standard drought indices (Bachmair, Stahl, et al., 2016). However, relatively little attention has been given to the socio-ecological responses to present and projected droughts (Wilby, 2020). An indicator of 'Total annual spend on resilience measures by all water companies' was reviewed by ADAS (2019) but not included in the final set of metrics reported by the Climate Change Committee (2021b). Moreover, it has been noted that

> ...while impacts are often used to define drought, in the UK this is usually undertaken in hindsight rather than actively monitored and reported publicly...
>
> (Hannaford et al., 2019, p. 56).

Hence, there are gaps in UK capabilities to (1) report impacts of past and present droughts; as well as (2) build resilience to future drought risks. This paper considers how indicators—based on online searches—could help address these challenges and support water planning through more targeted public messaging around water conservation. The following section describes the data sources used to track online searches of drought-related terms, and the concurrent water situation, as measured by rainfall and river flow data for England, and newspaper reports of drought impacts in Ireland within the period 2011–2022. These countries were chosen for comparative purposes and to limit the possibility of contrasting drought/non-drought conditions over larger areas (such as the UK as a whole). We then discuss the potential usefulness and feasibility of developing more nuanced indicators of drought impacts and societal awareness, in near real-time.

## 2 | DATA SOURCES AND METHODS

We draw on three main sources of data: (1) volumes of online searches using drought- and heatwave-related terms; (2) conventional hydroclimatic metrics of precipitation and river flow; and (3) newspaper reports stratified by drought impact sector. The methods subsection then explains how information source (1) was correlated with sources (2) and (3) to evaluate associations between time-varying online search interest, long-term hydroclimatic data, and reported drought impacts.

### 2.1 | Online search terms and interest

Google Trends (GT) is a publicly available tool that enables analysis of the relative popularity of search terms over time. It provides data on the number of Google searches for a particular term that can be used to track changes in search volume for any topic. The data are anonymised, categorised and aggregated, allowing users to gauge interest in search terms or topics at global to city scales (assuming sufficient search volumes are available). Providing absolute search information would return billions of entries every day which would not be feasible to describe. Therefore, data are presented as a proportion of all searches on all topics on Google for the specified period and geographical unit, in a way that accounts for the changing numbers of interest users through time. GT has filters for real-time and historical datasets. Real-time searches cover the past 7 days, compared with non-real-time, which is a sample of the entire Google dataset from year 2004 to 36 h ago. This offers scope for following public interest in droughts and their impacts in near real-time (as in de Brito et al., 2020).

However, GT does have limitations. Although data aggregated by GT are referenced by geographical area, searches made by users may be for events that are taking place or have occurred in places remote from the physical location of the internet browser. For example, by using Google to search for information about 'drought' in Australia, a Loughborough-based user would add to England counts of searches on the topic of drought. In other words, counts reflect the geographical location of the *searcher* rather than the *search topic*—an effect that may confound associations. Moreover, spikes in search volumes for drought could be driven by other factors such as media coverage in another country or unrelated issues, for example, UK-based searches for the lyrics of a US-based Beyoncé song 'Love Drought'.

Despite these recognised limitations, there has been much uptake of GT in hydroclimatic research. For instance, Kam et al. (2019) used GT to analyse decay patterns in drought interest, whereas Kim et al. (2019) tracked drought awareness at regional and national scales across the United States by comparing search interest with data from the US Drought Monitor. Similarly, Park et al. (2022) found that spikes in public interests in drought depend on drought intensity. Others have used GT to investigate growing public health concerns about micropollutants in waste, surface or groundwater in the UK (Mavragani et al., 2016); or around heat-health vulnerabilities in Ireland (Paterson & Godsmark, 2020). At the

other hydrological extreme, Thompson et al. (2022) demonstrated that GT could help evaluate flooding in places (Kenya and Uganda) where formal hydro-meteorological data are scarce.

## 2.2 | Hydroclimatic data

Two datasets were used to characterise the long-term water situation in England. They were the Met Office HadUKP precipitation series[2] and the National Hydrological Monitoring Programme (NHMP) Outflow Series.[3] For Ireland, monthly total precipitation data were obtained from the updated Island of Ireland Precipitation series (Murphy et al., 2018; Noone et al., 2016). All these series were chosen because they provide a high-level overview of precipitation and runoff anomalies at spatial and temporal scales compatible with the GT output.

## 2.3 | Newspaper articles

The Irish Drought Impacts Database (IDID) (Jobbová et al., 2023) is an existing catalogue of historical drought impacts compiled from print media covering the period 1733–2019. The IDID comprises more than 11,000 drought impact reports, identified and categorised through systematic searches of the Irish Newspaper Archives[4] (INA) using key terms such as 'drought' and 'droughts'. The INA provides a good sample of national and regional print media from at least 50 titles annually covering the majority of Irish counties, but is not an exhaustive database of all Irish newspapers. Identified newspaper reports were previously examined to remove irrelevant articles, such as those referring to the surname 'Drought' or a 'scoring drought' in sporting terms. Remaining articles were then formerly grouped into 15 drought impact categories using a modified version of the impact categories developed as part of the European Drought Impact Inventory (Stahl et al., 2012). This includes agriculture and livestock farming, forestry, energy and industry, tourism and recreation, public water supply (PWS), water quality, freshwater ecosystem (habitats, plants and wildlife), terrestrial ecosystem (habitats, plants and wildlife), soil systems, wildfires, air quality and human health. The date of impact, date of report, newspaper title, associated drought categories and subcategories, location of impact (local area, county, region), timing of impacts and relevant quotations from the article are provided for each impact (where available) in the IDID. Hence, the dataset yields detailed information about the temporal and geographical extent of drought events, their socio-economic context, impacts and responses.

Although the IDID provides valuable information on drought impacts, the database has several limitations (Jobbová et al., 2023), including changing frequencies of publication, variations in lifespan, and spatial coverage of newspaper titles in the INA. For our period of analysis (2011–2019), the annual number of newspapers in the INA remains stable at more than 60 titles. However, a predominance of regional newspapers in some counties and larger centres of population may create biases through increased reporting in those areas. While the IDID includes Northern Ireland, there are fewer titles there relative to the Republic.

More generally, use of newspaper records for investigating drought may introduce other biases, such as editorial judgements about what is newsworthy at the time and alongside other stories. The number of impact reports also varies markedly between impact categories and is dominated by articles about agriculture, livestock and PWS. No doubt this reflects the importance of these sectors in Ireland, but the focus also reveals what is considered as important from a journalistic perspective so should not be considered a comprehensive representation of wider drought impacts. Digitalisation and hybrid news landscapes have also influenced gatekeeping and curation of content by legacy media (Ismail et al., 2019). For instance, editors may now draw on official sources and experts alongside social media posts for 'eyewitness accounts' of extreme weather (e.g., Strauss et al., 2022). Hence, there is a dynamic, two-way relationship between the framing of events by online news and social media (Guggenheim et al., 2015) that could skew reporting of drought impacts by newspapers. Despite these issues, previous work shows that the IDID correlates well with formal meteorological and hydrological drought metrics in Ireland (Jobbová et al., 2023; O'Connor et al., 2022a, 2022b).

## 2.4 | Methodology

Here, we describe the application of GT, hydroclimatic series and IDID reports to discern societal and environmental impacts of droughts in England and Ireland. Following Hannaford et al. (2019), we are particularly interested in

the feasibility of using GT as a source of near real-time (rather than retrospective) indicators of socio-environmental drought impacts. Others have also called for a better framing of drought as a coupled dynamic between the environment and society (Bachmair, Svensson, et al., 2016, p. 516). with greater emphasis on indicators for drought monitoring and early warning.

GT allows the comparative analysis of up to five search terms. We began by exploring detailed variations in search interest for broad terms such as 'drought', 'heatwave' and 'hosepipe' over the period 2018–2022 as these years bracket three notable events (in 2018, 2020 and 2022) across the GT geographical domains of England and Ireland. We then evaluated a set of 25 terms, clustered into five thematic groups, each with five terms (Table 3). For example, our 'Household' group has search terms: 'dual flush toilet', 'grey water', 'tap aerator', 'water butt' and 'watering can'. Our initial choice of terms was informed by trial and error, as well as by reference to previous studies (e.g., Lee et al., 2022). Terms considered but subsequently excluded due to small sample sizes were: 'bottled water', 'desalinisation', 'drought index', 'Drought Order', 'river flow', 'runoff', 'soil moisture', 'water abstraction', 'water cycle', 'water deficit', 'water demand', 'water pricing' and 'water stress'. Other terms—such as 'river level'—were excluded because they more often associated with floods than droughts.

Monthly GT search interest data were then downloaded separately for the 25 terms in Table 3 for the period 2011–2022, for England and Ireland separately. This ensures that each term is self-calibrated within the range 0 (no search interest) through to 1 (the month with greatest search interest). Extracted series were detrended by the method of differencing, whereby a new series is created by taking the difference in GT values between successive months. These detrended series were then cross-correlated with others in the group, across the set as a whole, and with the two hydroclimatic indices for England, as well as the newspaper report counts for Ireland. Critical values for the Pearson correlation coefficient ($r_{crit}$) were adjusted using the Bonferroni correction given the large number of correlation tests performed. For instance, when performing 50 separate correlation tests, $r_{crit}$ increases from 0.16 ($p=0.05$) to 0.27 ($p=0.001$) for a sample size $N=144$ months and a two-tailed test.

The same 25 GT interest search terms were assessed for the domain of Ireland, but the government agencies listed in Group 2 were replaced with Irish equivalents (i.e., Department of Environment, Environmental Protection Agency, Commission for Regulation of Utilities, Northern Ireland Environment Agency, and Irish Water) for the period 2011–2019. Counts of monthly drought impact reports—based on date of impact rather than of publication—were extracted from the IDID for the most common impact categories (i.e., agriculture and livestock, PWS, freshwater ecosystems and wildfires). Both datasets were detrended using the method of differencing, and resultant series cross-correlated. GT search terms that correlated significantly with the selected IDID categories were then identified, firstly using the $r_{crit}$ value of 0.19 ($p=0.05$) and then a more stringent ($p=0.001$) Bonferroni corrected $r_{crit}$ value of 0.33 (sample size $N=108$; two-tailed test). All four categories showed significant correlations with at least one GT interest term, with the most strongly correlated terms being 'hosepipe ban', 'water shortage' and 'water butt' (in that order). Detrended series for these GT search terms were subsequently plotted against impact reports to visualise their association.

Finally, we analyse impact reports from the IDID for a period concurrent with GT data (2011–2019). This includes 178 reports across the impact categories (Figure 2). We used these data to test the hypothesis that GT data correlate with reported drought impacts. The significance of the summer 2018 drought is immediately apparent from the spike in newspaper reports during this period. Overall, the most frequent impacts were reported for agriculture and livestock and PWS categories. The most frequently recorded subcategories, representative of the type of impact identifiable in the

**TABLE 3** Groups of search terms. Those with greatest interest in each group during 2018–2022 are highlighted in bold. Note that Group 2 organisations were changed for equivalent organisations in Ireland (see section 2.4). SEPA is included in the analysis of Google Trends (GT) data for England to cover transboundary river catchments.

| Group 1 | Group 2 | Group 3 | Group 4 | Group 5 |
|---|---|---|---|---|
| **Households** | **Organisations** | **Impacts** | **Regulation** | **Hydrological** |
| Dual flush toilet | Defra | Algae bloom | **Hosepipe ban** | Groundwater |
| Grey water | **Environment Agency** | Heath fire | Water customer | Infiltration |
| Tap aerator | Ofwat | Subsidence | Water meter | Irrigation system |
| **Water butt** | SEPA | **Water leak** | Water supply | Water evaporation |
| Watering can | Water company | Water shortage | Water use | **Water management** |

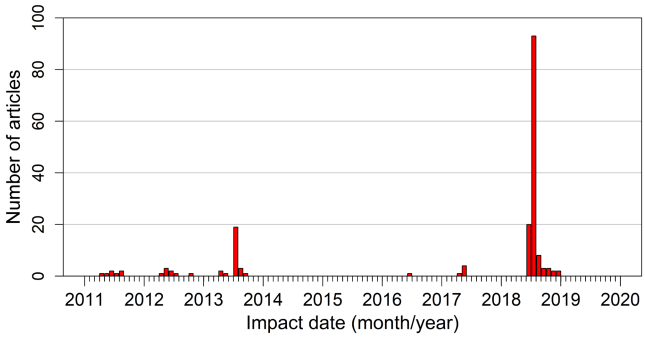


**FIGURE 2** Number of Irish Drought Impacts Database (IDID) drought impact reports, by month of impact, across all categories during the period 2011–2019.

given article, were reduced crop productivity and local water supply shortages. Notably, nine categories had fewer than 10 impact reports so were excluded from the correlation analysis.

## 3 | RESULTS

The findings of the GT, hydroclimatic series and newspaper archive analysis are presented in three stages. First, the relative interest and intra-annual phasing of key search terms are described. Second, multi-annual trends and correlations among terms are presented. Third, the strongest associations between GT interest versus hydroclimatic series for England and drought impacts in Ireland were identified.

### 3.1 | Intra-annual variations

Over the periods 2018–2022 and 2011–2022 there was more interest in 'heatwave' than 'drought' with GT search volumes 69%–72% and 28%–31% of the totals, respectively, in the four nations of the UK (compared with a more even divide of 42%–60% and 40%–58% across regions of Ireland). Interest in 'hosepipe ban' in England peaked in April 2012, July 2018 and August 2022, coinciding with actions taken by water companies to preserve stocks at those times (Figure 3). The largest spike in the Ireland series occurred in July 2018—the month when a state of absolute drought was declared in the Republic because there had been no rainfall at the vast majority of weather stations in the previous 14 days.

There were subtle variations in the timing of maximum interest within and between years (Figure 4). In England, this was most marked during summer 2022 when interest in the record-breaking heatwave[5] peaked in 17–23 July, 3 weeks before greatest interest in drought (and hosepipe bans) in 7–13 August. Conversely, in 2018 and 2020, peak interest in drought (and hosepipe bans) preceded peak interest in the heatwave due to exceptionally dry conditions in June and spring respectively. Hence, the GT data can detect and discriminate variations in the temporal evolution of the two hazards between years.

### 3.2 | Inter-annual variations and correlations

Other trends emerge over the longer term among some of the 25 search terms (Figure 5). Overall, 'hosepipe ban' (Group 4) attracts most interest, but this is highly episodic. Within other groups the most popular terms were 'water butt' (Group 1), 'Environment Agency' (Group 2), 'water leak' (Group 3) and 'water management' (Group 5). Strong upward trends are evident in the volume of searches for all household terms (Group 1), but most notably for 'dual flush toilet', 'grey water' and 'tap aerator'. Interest in 'water butt' and 'watering can' has increased too, but is highly seasonal with clear summer maxima. Searches for organisations (Group 2) has waned across the years, with notable declines for 'Defra' and 'Environment Agency'. Intervening spikes of interest during winters 2013/14, 2015/16 and 2019/20 coincided with major flood episodes. Search interest in impacts (Group 3) has risen most for 'water leak', but there are also spikes in search volumes for 'water shortage'. All regulation terms (Group 4) show a strong increase (except 'hosepipe ban') with significantly more interest in 'water use' and 'water meter' in 2022 than in 2011. Search

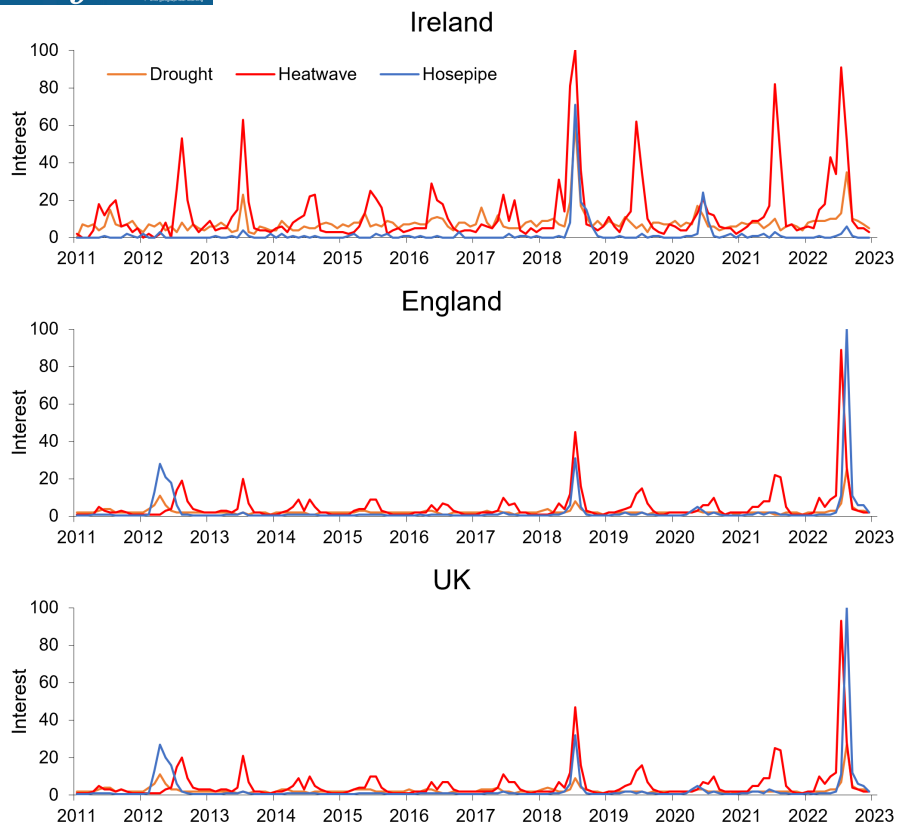


**FIGURE 3** Google trends (GT) interest in search terms 'drought' (orange line), 'heatwave' (red line) and 'hosepipe' (blue line) in Ireland, England and the UK during the years 2011–2022, having normalised across the period as a whole. Note that GT system changes were made to data collection in 2016 and 2022.

volumes for hydrological terms were comparatively low and noisy apart from 'irrigation system', which is highly seasonal and typically peaks in May–July.

Within groups, there were significant ($p=0.001$) correlations among detrended search data for 'water butt' versus 'watering can' ($r=+0.60$); 'water leak' versus 'water shortage' ($r=+0.52$); 'water meter' and 'water use' ($r=+0.52$); and 'infiltration' versus 'water evaporation' ($r=+0.47$). Other significantly correlated pairs of terms were: 'grey water' versus 'water butt' ($r=+0.55$); 'heath fire' versus 'water shortage' ($r=+0.46$); 'hosepipe ban' versus 'water use' ($r=+0.48$); and 'groundwater' versus 'evaporation' ($r=+0.39$). Across all search terms, the strongest correlations were for 'hosepipe ban' versus 'water butt' ($r=+0.72$); 'hosepipe ban' versus 'water company' ($r=+0.69$); 'water shortage' versus 'water supply' ($r=+0.65$); and 'watering can' versus 'irrigation system' ($r=+0.65$). For example, when there is high interest in hosepipe bans people are also searching for information about water butts—perhaps as an adaptation measure. Similarly, the strong association between watering can and irrigation system could reflect concerns about dry soils and damage to garden plants/crops (Figure 6).

## 3.3 | Correlations with hydroclimatic data and newspaper reports

We investigated associations between GT search volumes and hydroclimatic series for England (coincident and lagged in time), and documented impacts in Ireland. The strongest negative correlations were between preceding (lag-1) monthly England and Wales Precipitation (EWP) and 'water butt' ($r=-0.42$), 'watering can' ($r=-0.28$), 'heath fire' ($r=-0.28$) and 'irrigation system' ($r=-0.31$); the only significant positive correlation was for 'Environment Agency' ($r=+0.27$). The strongest negative correlations with the non-lagged monthly England Outflows series were also for 'water butt' ($r=-0.45$), 'watering can' ($r=-0.32$), 'heath fire' ($r=-0.23$) and 'irrigation system' ($r=-0.40$). The strongest positive correlations were for England outflows and 'Environment Agency' ($r=+0.51$), and 'groundwater' ($r=+0.38$).

Inspection of the data for selected search terms suggests non-linear associations with the rainfall and runoff series (Figure 7). For instance, search volumes for 'drought' increase markedly when the EWP total for the previous month is <50 mm, or when England outflows for the concurrent month are <500 $m^3/s$. Interest in 'irrigation system' falls

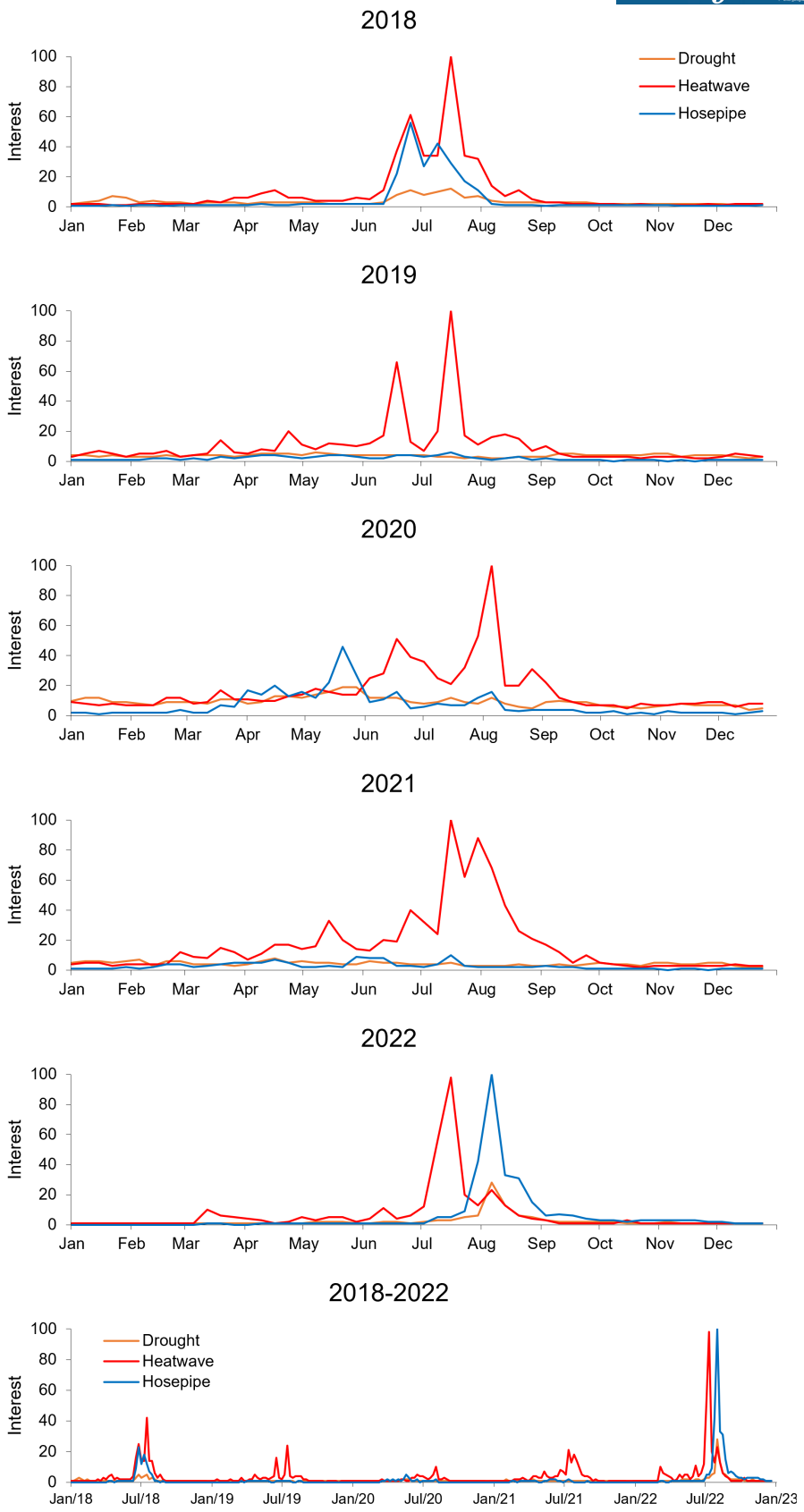


**FIGURE 4** As in Figure 3 but for England during years 2018–2022, normalised over this whole period. Note the data collection system changed from 1 January 2022.

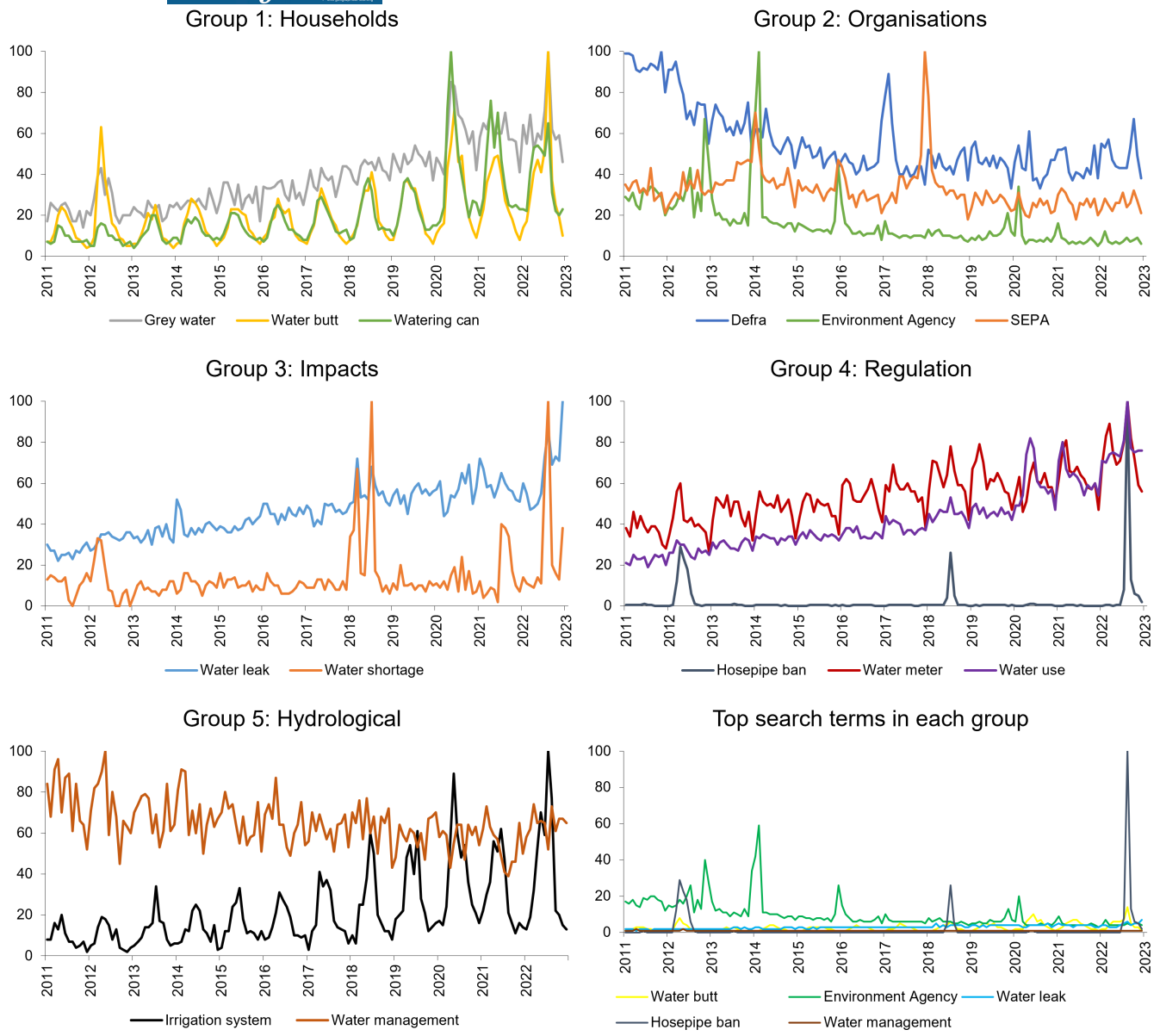


**FIGURE 5** Long-term variations in Google Trends (GT) search interest around 'households' (grey water, water butt, watering can), 'organisations' (Defra, Environment Agency, SEPA), 'impacts' (water leak, water shortage), 'regulation' (hosepipe ban, water meter, water use), and 'hydrological' (irrigation system, water management) terms in England over the period 2011–2022. Changes in comparative volumes are also given for the most popular search terms in each group (lower right panel).

dramatically when the monthly mean outflow is >1000 $m^3/s$. As noted previously, interest in the 'Environment Agency' tends to peak during flood episodes.

In Ireland, the terms 'hosepipe ban', 'water shortage' and 'water butt' were most strongly associated with the number of newspaper reports about drought impacts on agriculture/livestock, PWS, freshwater/terrestrial, soils and wild fires (Figure 8). This suggests that GT terms such as 'hosepipe ban' are good proxies for historical attention by (print) media to agricultural/livestock and PWS (most notably in summer 2018). Intriguingly, there were no significant correlations between GT search terms and total monthly precipitation for Ireland.

Two other points emerge from this analysis. First, the correlation between the GT data for 'hosepipe ban' and each of the IDID categories was strong ($r > 0.7$) relative to other terms—as shown by the steeper gradients for this term in Figure 8. Second, agriculture and livestock, and PWS are prominent because of the greater number of impact reports within the period 2011–2019 when compared with all other categories (which had less than 10 articles each in the same period).

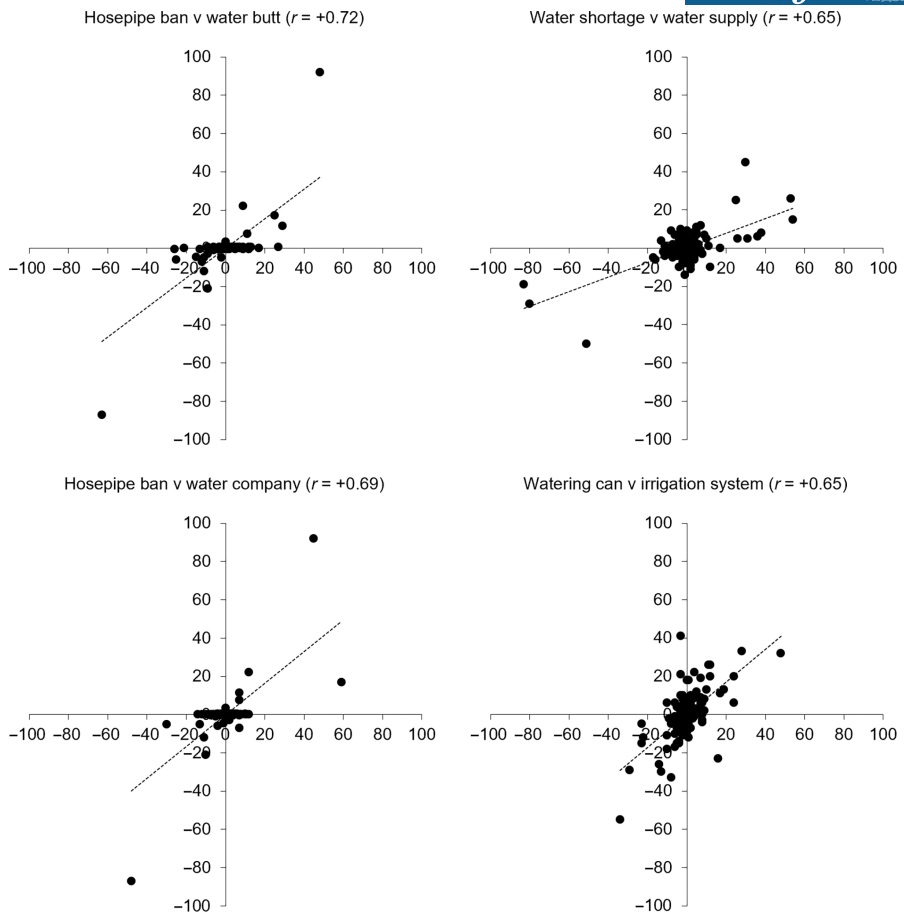


**FIGURE 6** Google Trends (GT) interest among drought-related search terms for England over the period 2011–2022. Each data point shows coincident GT interest in the search terms (such as amount of interest in 'hosepipe ban' at the same time as 'water butt') for a single month. All data were detrended. Correlations (*r*) are shown in brackets.

## 4 | DISCUSSION

Our analysis shows that GT search interest around drought terms is a good indicator of water availability and drought impacts—as evidenced by significant correlations with (1) national precipitation and outflow series for England and (2) counts of newspaper reports of selected drought impacts in Ireland, as comparators. Furthermore, long-term trends in GT search terms uncover changing public search interest around droughts. For example, GT data since year 2011 reveal upward trends in search interest around several themes, most notably for 'grey water', 'water leak', 'water meter' and 'water use'. This suggests that searches have been focused more on outdoor water saving than indoor measures (as the interest volumes decrease from water butt > watering can > grey water > dual flush toilet/tap aerator > water saving shower head). Interest in search terms such as 'water butt' and 'irrigation system' is also weakly but significantly correlated with national precipitation and runoff series for England.

Findings that are potentially relevant to water agencies, policy-makers and water companies include:

- Public interest in water saving: rising search interest in water saving technologies could suggest a growing curiosity about household-level solutions to water scarcity during droughts.
- Public attention to outdoor water: greater search interest around outdoor water measures than indoor measures may signal opportunities for more targeted public information campaigns.
- Public information seeking from agencies: search interest in Defra and the Environment Agency is more associated with floods than droughts, hence public relations teams might consider ways of improving awareness of roles played by these organisations during droughts.
- Public information seeking about companies: search interest in water companies in England is more likely to be associated with hosepipe bans than water leakage (although this varies by company).

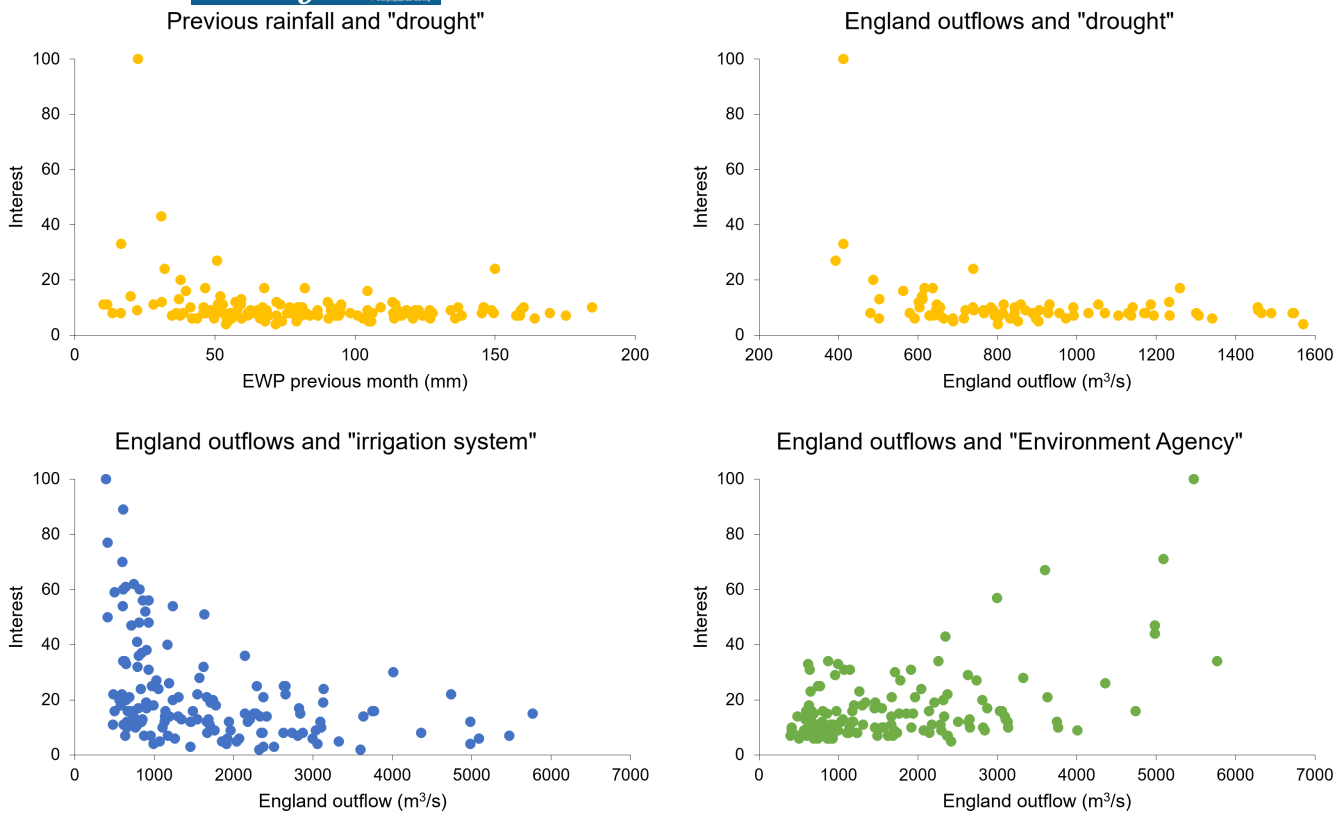


**FIGURE 7** Google Trends (GT) interest in the search terms 'drought', 'irrigation system' and 'Environment Agency' coinciding with the amount of England and Wales precipitation (EWP) in the previous month or all England outflow. Each data point represents a single month in the period 2011–2022.

These insights could lead to the development of new indicators to inform water planning and drought management. For instance, real-time GT data on searches for outdoor water saving and use (i.e., water butts and cans, grey water) plus irrigation systems might track the rising severity of a meteorological drought. Our evidence from Ireland suggests that these terms could also reflect evolving impacts on agriculture, livestock and PWS, as well as harm to natural freshwater and terrestrial environments. Rising volumes of searches about water leakage and metering, paired with water use and shortages, may signal greater public disquiet and awareness of the links between these issues and hence scope for policy interventions. This could be a manifestation of evolving notions of water consumer rights and responsibilities (Taylor et al., 2009). Variations in the phasing of relative interest in drought and heatwave may also capture shifting societal concerns during an event—signatures that are unique to each heat-drought episode. Water companies might note that searches for their names (principally Thames Water, Southern Water, Anglian Water, Severn Trent Water, Yorkshire Water) frequently associate with interest in hosepipe bans and meters.

Other potential uses of the near real-time capability of GT data for water management are:

- Detecting secondary effects: droughts have primary and secondary impacts. Although primary effects (such as water scarcity) are often anticipated, secondary effects (such as heat-related illnesses) might be overlooked. GT has long been used to monitor online health-seeking behaviour (e.g., Ginsberg et al., 2009) and could be extended to detecting mental health impacts of droughts on vulnerable groups (Vins et al., 2015).
- Analysing real-time sentiment: GT offers a live window into public sentiment. This allows authorities to gauge public concern, awareness and potential areas of panic or misinformation. For instance, GT has previously been used to track public concerns around the economy and employment (e.g., Chen et al., 2015), or to forecast consumer behaviour (e.g., Choi & Varian, 2012).
- Targeting communication: GT can pinpoint regions with heightened search activity around drought topics. Such information could be used to target messaging on water saving at times and places with peak public interest in drought or ensure that information campaigns are geographically relevant.

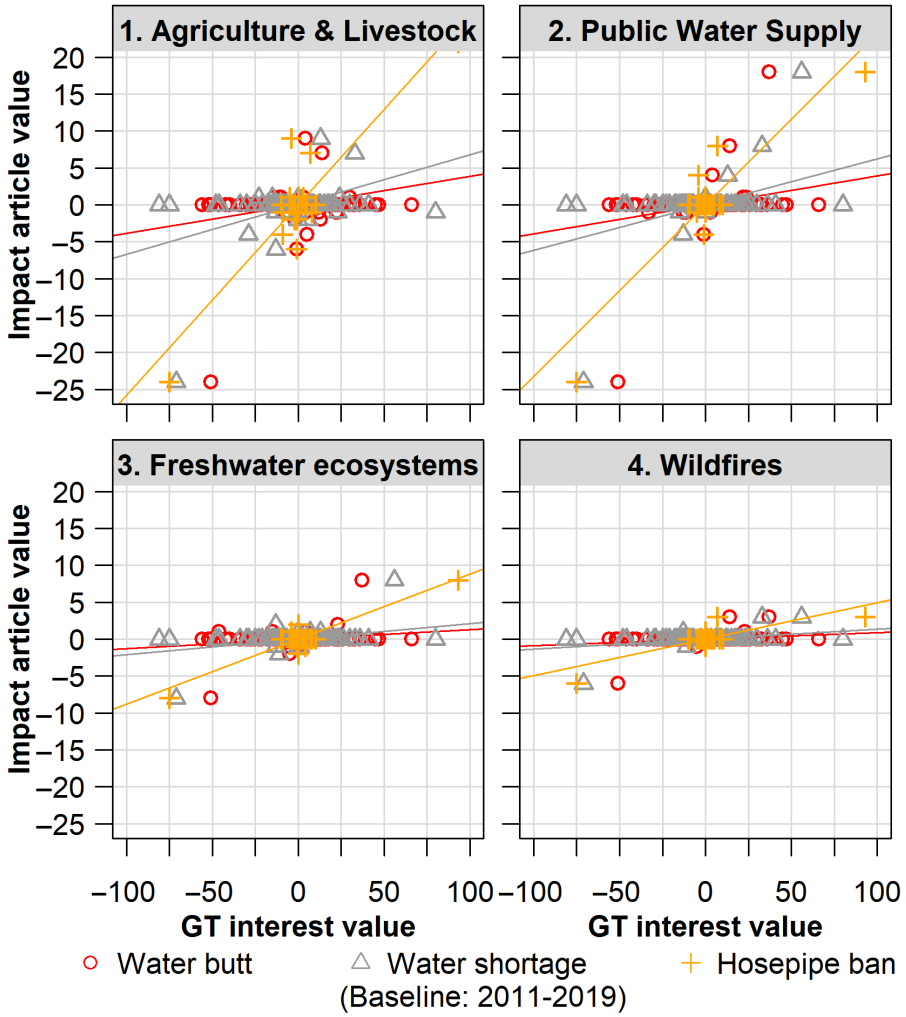


**FIGURE 8** The number of drought impact articles (for IDID categories with >10 reports) in Ireland coinciding with Google Trends (GT) search interest in the terms 'water butt', 'water shortage' and 'hosepipe ban'. Each data point represents a single month in the period 2011–2019. All data were detrended.

- Assessing effectiveness of campaigns: as well as targeting information, GT data could also be used to gauge the successfulness of specific campaigns—such as by tracking interest in campaign keywords or phrases as an indicator of message visibility, reach and/or public engagement.
- Adjusting policies: water policies can have intended and unintended consequences. A surge in online searches related to a recently introduced measure (such as a hosepipe ban) could be used to track public reactions which might span intrigue, confusion or dissatisfaction. This could support more agile policies and information campaigns.
- Busting myths: in crisis situations, misinformation can spread rapidly and exacerbate the situation. For example, the term 'Day Zero' contributed to near-panic during the 2016–2018 Cape Town drought (Enqvist & Ziervogel, 2019). GT could act as an early warning for trending misconceptions or myths, and thereby assist authorities in building public trust and avoiding misguided actions.

GT data appear to cover most of the desirable attributes for an indicator given in Table 1. Search volumes are benchmarked (individually or relative to other terms); sensitive to hydroclimatic conditions (as evidenced by correlations with rainfall and runoff); based on free and open data that are updated in real-time; reflective of changes in public engagement; and yield insights that are decision relevant (around messaging, marketing and water consumer behaviour). Although GT data are available from 2004, there have been several unspecified system changes since then (most recently on 1 January 2022) so the homogeneity of GT series is uncertain. Moreover, information-seeking behaviour is shaped by many factors, such as awareness of event onset and characteristics of the subject matter or product (Jun et al., 2018). Hence, there is a raft of factors that potentially confound interpretations.

Our findings and suggestions should be treated with caution because of other specific shortcomings of GT data. For example, particular search terms can have multiple meanings: 'runoff' cannot be included because of links to electoral runoffs (in the US State of Georgia, and Senate); and 'showering' is biased by searches for Nic Showering (one of The Apprentice 2022 contestants). Some data are even available for misspelt terms such as 'drout'! The term 'water cycle' has strong intra-annual variations that might be attributable to school coursework and examinations. As might be expected, there are relatively few searches and hence robust data for technical terms like 'river pollution', 'water saving', 'water level' and 'public water supply'. Search term generation and online searching behaviour are known to be influenced by age, gender, cognitive biases and other individual characteristics (Ford et al., 2001; Urman & Makhortykh, 2023). The geographical domain of GT data also reflects the location of the searcher rather than the subject matter. Finally, it must be kept in mind that public interest in a drought-related topic—such as water-saving devices for the home or leakage from the water distribution network—does not necessarily translate into changes in household behaviour or expenditure.

Another important caveat is that online search terms can have multiple motivations and interpretations. For example, online searches for 'hosepipe ban' could be driven by those seeking to comply with or evade water restrictions; those concerned about protecting their gardens or business; those redoubling efforts to save water; those researching customer rights and penalties; or combinations of all these reasons and more. Associated search terms may help to unbundle these various impetuses. For instance, the strong correlation ($r = +0.72$) between GT data on 'hosepipe ban' and 'water butt' may signal that many searches are prompted by a desire for greater preparedness but further investigation would be required to confirm this possibility.

Despite these reservations our analysis shows the potential for GT data to inform water planning and drought management. The UK still lacks a one-stop-shop, public domain, environmental indicator set because the need to make an economic case for this remains a persistent obstacle. Nonetheless, techniques are being developed for valuing climate services, including when building climate resilience (Watkiss & Hunt, 2021). Some assert that resilience metrics and indicators are important tools for tracking risks and climate actions (Wilby, 2020). Others claim that the things we really care about are not always quantifiable:

> Measurement requires stopping the action, getting outside of it and holding it up against a yardstick, exactly the opposite of the activity that would create products or ship them, make customers happy or move our business forward in any way
>
> (Ryan, 2014).

However, we assert that the economy, immediacy and intimacy of GT makes this a powerful tool worthy of further evaluation for environmental applications, including drought management.

## 5 | CONCLUSIONS

This paper began with an overview of the rationale and use of indicators by the water sector to reduce disruption to supplies and harm to the environment. Drought-related risks are also embedded in many national climate change indicators. However, in the UK, there remain major gaps in capabilities to track socio-environmental impacts of droughts (in near real-time) as well as for monitoring progress in building resilience to future drought risks. Considerations of cost, immediacy, access, consistency, relevance, reliability and others have to be addressed when evaluating the suitability of information for indicators. Here, we show the largely untapped potential of Google Trends (GT) data as a resource for developing drought indicators.

Our preliminary analysis for England and Ireland shows that GT search interest can track the temporal evolution of drought and heatwave hazards, along with changes in online information seeking about associated impacts and adaptation measures. Search volumes for terms such as 'water butt' and 'hosepipe ban' are significantly correlated with conventional hydroclimatic data. There is also evidence of longer-term growth of interest in water saving technologies and techniques, especially around outdoor water use. Less interest around indoor water appliances may present opportunities for future resilience building measures and incentives. However, we are mindful that other factors influence Google searches, not least the characteristics and motivations of the user, and that GT data have limitations.

Nonetheless, our analysis yields other insights, such as the low association between 'Environment Agency' and 'drought', or high association between queries about water companies and hosepipe bans. Such knowledge could help shape public information campaigns and corporate branding. More specifically, GT indicators could be used to detect secondary drought impacts; analyse public sentiment in near real-time; target sensitised audiences and regions with

drought communications; assess the effectiveness of such campaigns and adjust policies accordingly; as well as spot misinformation or misguided actions. The GT analysis for Ireland could also be replicated using drought impact reports within existing newspaper archives for England. Another possibility worthy of exploration is the potential of media-based drought indicators to support impact-based forecasting. As with public health and the economy, it may be possible to predict upticks in public water demand (or saving) by analysing online search behaviour.

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## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available from Google Trends at https://trends.google.com/trends/?geo=GB.

## ORCID

*R. L. Wilby* https://orcid.org/0000-0002-4662-9344

*J. J. Thompson* https://orcid.org/0000-0002-0177-4046

## ENDNOTES

[1] Whether there are any 'natural' hazards is now questionable given the extent of human-induced global change – but we shall overlook this oxymoron.

[2] https://www.metoffice.gov.uk/hadobs/hadukp/data/download.html.

[3] UKCEH National River Flow Archive, *pers. comm.*

[4] https://www.irishnewsarchive.com/.

[5] A new temperature record of 40.3°C was set on 19 July 2022 at Coningsby, England.

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