Report No. **519**

CRISIS - Climate Change in the Republic of Ireland: Societal Impacts and Solutions

Authors: Jean O'Dwyer, Carlos Chique, Martin Boudou, Marguerite Nyhan, Stig Hellebust, Anushree Priyadarshini and Paul Hynds

Lead organisation: University College Cork and Technological University Dublin

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Rialtas na hÉireann
Government of Ireland

Environmental Protection Agency

The EPA is responsible for protecting and improving the environment as a valuable asset for the people of Ireland. We are committed to protecting people and the environment from the harmful effects of radiation and pollution.

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4. Office of Radiation Protection and Environmental Monitoring
5. Office of Communications and Corporate Services

The EPA is assisted by advisory committees who meet regularly to discuss issues of concern and provide advice to the Board.

epa Research

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What did the research aim to address?

The CRISIS project aimed to address a critical knowledge gap regarding how climate change is impacting human health and wellbeing in Ireland, both now and in the future. While climate-related risks are well recognised globally, there has been limited integrated, Ireland-specific evidence linking extreme weather events (EWEs), environmental exposures, and public health outcomes. This research was therefore designed to generate a comprehensive, evidence-based understanding of these relationships to inform national policy and preparedness. The study is important for policymakers, public health professionals, environmental agencies, and vulnerable communities, as it identifies who is most at risk and why. It responds to growing concerns about increasing floods, heatwaves and droughts, and their implications for mental health, water quality, and infectious disease transmission. The project adopted an innovative, interdisciplinary approach, combining national survey data, epidemiological analysis, spatial modelling and climate projections. This integrated framework enabled the linking of environmental drivers with both physical and psychological health outcomes, while also projecting future risks. By combining multiple data sources and advanced analytical techniques, the research provides a robust evidence base to support climate-resilient public health strategies in Ireland.

What did the research find?

The CRISIS project found that climate change is already having measurable impacts on public health in Ireland, particularly through extreme weather events (EWEs), waterborne disease, and mental health. National survey results showed that EWEs significantly affect psychological wellbeing, with younger, urban and socioeconomically disadvantaged groups experiencing the highest stress levels. Epidemiological analyses identified clear links between flooding and increased cases of Verotoxigenic producing E. coli (VTEC) and Cryptosporidiosis, while the 2018 heatwave coincided with elevated infection rates and shifting disease patterns. These findings directly address the previous lack of integrated, Ireland-specific evidence by demonstrating how climate and health are interconnected across multiple pathways. The research is highly relevant for policymakers and public health stakeholders, supporting improved disease surveillance, climate adaptation planning, and targeted interventions for vulnerable populations. Engagement with governmental agencies (e.g. HSE) helped ensure policy relevance and uptake. The project advances current knowledge through its novel integration of survey data, spatial epidemiology, and climate modelling to project future health risks. However, some limitations include reliance on self-reported survey data and potential underrepresentation of vulnerable groups. Overall, the research provides a robust evidence base for climate-resilient public health policy in Ireland.

How can the research findings be used?

CRISIS provides a strong evidence base to support climate-resilient public health policy and practice in Ireland. Findings can be used by government departments, public health agencies, and local authorities to inform climate adaptation strategies, particularly in areas such as water quality management, disease surveillance, and emergency preparedness. For example, integrating climate data into early warning systems can help anticipate disease outbreaks following extreme weather events, while targeted mental health supports can be embedded within disaster response frameworks. Next steps include translating findings into actionable policy through cross-sector collaboration, strengthening monitoring systems, and investing in resilient infrastructure, particularly for vulnerable groups such as private well users. The research also supports the development of public awareness campaigns on safe water and food practices during extreme events. The work is already aligned with national climate and health policy priorities and offers opportunities for integration into future adaptation plans and risk assessments. However, further research is needed to refine predictive models, improve real-time data integration, and better capture impacts on underrepresented populations. Continued stakeholder engagement will be essential to ensure effective implementation and long-term environmental and public health outcomes.

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CRISIS – Climate Change in the Republic of Ireland: Societal Impacts and Solutions

(2019-CCRP-MS.62)

EPA Research Report

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Prepared by

University College Cork and Technological University Dublin

Authors:

Jean O'Dwyer, Carlos Chique, Martin Boudou, Marguerite Nyhan, Stig Hellebust, Anushree Priyadarshini and Paul Hynds

ENVIRONMENTAL PROTECTION AGENCY
An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699
Email: info@epa.ie Website: www.epa.ie

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This report is based on research carried out/data from 2020 to 2023. More recent data may have become available since the research was completed.

The EPA Research Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Project Partners

Jean O'Dwyer
University College Cork
Cork
Ireland
Email: Jean.ODwyer@ucc.ie

Carlos Chique
University College Cork
Cork
Ireland

Martin Boudou
Technological University Dublin
Dublin
Ireland

Margeurite Nyhan
University College Cork
Cork
Ireland

Stig Hellebust
University College Cork
Cork
Ireland

Anushree Priyadarshini
Technological University Dublin
Dublin
Ireland

Paul Hynds
Technological University Dublin
Dublin
Ireland

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Executive Summary

The Climate Change in the Republic of Ireland: Societal Impacts and Solutions (CRISIS) project offers the first integrated assessment of the societal and public health impacts of climate change in Ireland. Drawing on national surveys, time-series infection data, spatial modelling and climate projections, the research demonstrates how extreme weather events (EWEs) and changing climate patterns are affecting Irish communities and how their effects are likely to intensify in the future. Key focus areas include psychological well-being, waterborne disease transmission and the projected health burden of climate change.

A major component of the study was a national survey on climate and health ($n = 456$) that assessed the psychological effects of EWEs, such as floods, storms and heatwaves. The survey found that 51% of respondents reported worsened health, 57.7% reported financial difficulties and 56.2% experienced injury to themselves or family members due to EWEs. Using the Impact of Event Scale – Revised to assess psychological distress, respondents aged 18–25 were found to score a median of 44, compared with a median score of only 6 among those aged over 65, indicating significantly higher psychological stress among younger populations. High stress scores were also associated with lower income (<€20,000 per year group median score: 38) and lower education levels (primary education group median score: 49, vs postgraduate group median score: 11.5). The study identified four psychological stress clusters, with the "high-stress" group more likely to be younger, urban-dwelling, financially impacted and lacking third-level education.

In terms of physical health, the study quantified the impacts of two major climate events: the 2015–2016 winter floods and the 2018 European heatwave. The 2015–2016 floods corresponded with significant residual peaks in verotoxigenic *Escherichia coli* (VTEC) (+23 cases) and *Cryptosporidium* (+57 cases) infections in April 2016. Space–time analyses identified three significant VTEC enteritis clusters and eight cryptosporidiosis clusters during the flood period, many of which overlapped with the Shannon River Basin. Time-lagged analysis showed associations between infection rates and hydrometeorological variables, particularly surface water discharge and rainfall, with peak impacts occurring 12–19 weeks after flood events. The 2018 drought coincided with a sharp rise in VTEC cases, including 27 excess cases in June 2018 alone. Notably, the O26 serotype accounted for 30.8% of VTEC cases during the drought, compared with 24.2% in other periods, suggesting a potential drought-linked shift in strain dominance.

Looking ahead, climate modelling reveals significant public health risks associated with future temperature and rainfall scenarios. Projections show that Ireland's mean temperature may increase by 1–1.6°C by 2100, with summer and winter increases reaching +2.6°C and +3.1°C, respectively, relative to pre-industrial levels. Monte Carlo simulations suggest that under a +2°C warming scenario the number of VTEC clusters could increase by 219%, while a 20 mm increase in rainfall could lead to a 127% increase in cryptosporidiosis clusters and a 117% increase in VTEC clusters. Generalised linear modelling confirmed temperature and rainfall as significant predictors, with odds ratios of 6.82 for temperature and 1.025 for rainfall in VTEC enteritis incidence, and 2.66 and 1.09, respectively, for cryptosporidiosis.

The report concludes that climate change is already impacting public health in Ireland and that its effects will worsen without proactive policy intervention. Key recommendations include the integration of mental health supports into disaster response systems; enhanced disease surveillance; improved water infrastructure, particularly for private well users; and national public health campaigns targeting safe food and water practices. Additionally, the study calls for investment in real-time pathogen monitoring and the development of early warning systems for climate-driven disease outbreaks. Strengthening cross-sector collaboration among health, environmental and planning authorities is deemed essential to ensure a coordinated and effective response to emerging climate–health challenges.

1 Introduction

1.1 Project Context and Aim

Climate change is a complex phenomenon that mediates both direct and indirect impacts on society and public health. The most apparent (direct) health risks derive from extreme events, particularly heatwaves, storms, cyclones, fires, droughts and floods. In the medium to longer term, however, the wider (indirect) spectrum of health consequences resulting from climate change will encompass shifts in patterns of various infectious diseases (Patz *et al.*, 2005); changes in regional food yields (Wheeler and Von Braun, 2013); health consequences of diminished water flow and quality (Gosling and Arnell, 2016); and the deterioration of ambient air quality (Kan *et al.*, 2012), particularly in urban areas. Put simply, when climatic conditions change over time, we should expect changes in the patterns of exposures, health risks and population health profiles. Consequently, benchmarking the overall health of a population relative to climatic conditions is fundamental to establishing spatiotemporal risk profiles in a changing climate. In Ireland, the impacts of climate change are multifaceted. The temperate, oceanic climate of the island of Ireland, in concurrence with a stark urban–rural divide, allows multiple stressors to co-exist across relatively small land areas. For example, in rural areas, approximately 750,000 private well users are at increased risk of waterborne verotoxigenic *Escherichia coli* (VTEC) infection, with meteorological events, such as persistent and heavy rainfall, found to be associated with VTEC infection outbreaks (Óhaiseadha *et al.*, 2017). In contrast, in urban areas, meteorological variables such as temperature, humidity, wind speed/direction and mixing height play important roles in determining patterns of air quality over multiple spatiotemporal scales. The most significant pollutant identified by the European Environment Agency is particulate matter (EEA, 2019), with 1200 annual premature deaths reportedly attributable to particulate matter exposure in Ireland (EPA, 2018). Indeed, there is growing recognition that the development of optimal strategies to control future levels of key health-relevant pollutants such as ozone and fine particles ($PM_{2.5}$) should incorporate assessments of potential future climate conditions (Haines *et al.*, 2006). Compounding the physical impacts of climate change are myriad psychosocial impacts, which have detrimental effects on well-being, particularly among those most at risk (e.g. socioeconomically disadvantaged, geographically vulnerable). In spite of a general global awareness that climate change can affect public health and well-being, there is an urgent need to substantially increase our understanding of the diverse and wide-ranging impacts specific to Ireland, identifying vulnerabilities that currently exist and may exist in the future. In this context, the overarching goal of the Climate Change in the Republic of Ireland: Societal Impacts and Solutions (CRISIS) project was to increase our scientific understanding of historical, current and likely future human health and well-being risks, exposures and outcomes associated with weather and climate. The data and knowledge produced provide a critical evidence base for informing current and future policy and mitigation efforts. This report summarises the major findings of the CRISIS project, covering:

- results from a national survey of human well-being using evidence-based psychological scales to identify and prioritise key risks associated with the direct and perceived impacts of extreme weather events (EWEs) in Ireland (Chapter 2);
- quantification of the mechanisms and impacts of EWEs and climate change-related exposures on physical health, identifying particularly susceptible regions, periods and sub-populations using a combination of novel statistical and machine learning methods (Chapter 3);
- forecasting the future human health burden of climate change scenarios in Ireland, identifying susceptible locations and times (Chapter 4).

2 National Climate–Health Survey

2.1 Rationale

The present research investigates the intersection of EWEs and mental health in Ireland, a critical area of research as climate change increases the frequency and intensity of such events globally (IPCC, 2022). EWEs, such as floods, storms and heatwaves, pose significant public health challenges, influencing both physical and psychological well-being. This study focused on identifying the demographic, geographical and socioeconomic factors associated with psychological stress in populations exposed to EWEs via statistical and cluster analyses (Batool *et al*., 2025). The findings aim to inform evidence-based interventions and policy decisions to mitigate mental health impacts on vulnerable groups in Ireland.

2.2 Method

A cross-sectional survey was developed consisting of a self-reported questionnaire targeting a random sample of the Irish general public, which was live for a 6-week period from April to May 2021. The questionnaire was hosted on an online platform (SurveyMonkey), with participants engaged through an invitation email. Ethical approval was granted by the University College Cork Social Research and Ethics Committee. The questionnaire was structured around four main sections:

- key socio-demographic data (e.g. age, gender, occupation);
- EWE exposure and impacts (e.g. EWE type, pre- and post-event health);
- mental health and well-being measures (the Impact of Event Scale – Revised (IES-R));
- additional information (e.g. location, socioeconomic variables).

The degree of EWE exposure was retrospectively evaluated using a 5-point Likert scale (0, none at all; 4, extremely), with information on the working definition of an EWE (e.g. intensity, event types) and direct exposure provided to assist respondents in gauging their own experience and perceived level of EWE exposure. EWE exposure within the survey developed highlighted physical, mental and financial impacts – all frequently reported risk factors identified in a recent review of the EWE psychopathology literature (Chique *et al*., 2021a). As an online self-selected survey, the study may be affected by sampling bias, with certain groups (e.g. individuals with internet access, higher digital literacy or greater interest in climate or mental health issues) more likely to participate. Although the final analytical sample size ($n = 456$) is adequate for the statistical methods used, it may under-represent harder-to-reach or more vulnerable populations, potentially limiting population-level representativeness.

2.2.1 Mental health and well-being measures

The IES-R (Weiss and Marmar, 1997) was used to retrospectively evaluate the impacts of EWEs on psychological “stress”. The self-reported IES-R is widely employed in the evaluation of psychological stress among individuals exposed to traumatic events. The measure consists of 22 Likert scale items (0, none at all; 1, a little bit; 2, moderately; 3, quite a bit; 4, extremely) with sub-scales representing the three main symptom clusters of post-traumatic stress disorder (PTSD) (i.e. intrusion, avoidance and hyperarousal). Participants were instructed to rate how distressing each item was according to the most recent EWE experienced. The IES-R is generally considered to be representative of PTSD symptoms and, due to the inclusion of the hyperarousal sub-scale, is deemed increasingly compliant with the PTSD criteria in the *Diagnostic and Statistical Manual of Mental Disorders* (fourth edition). The measure provides a raw maximum score of 88 for all items, with higher values generally reflective of greater psychological distress. Some investigations employ tentative cut-off scores for PTSD (Asukai *et al*., 2002; Creamer and O’Donnell, 2002); for example, a raw score of 33 is often employed as an indicator of probable clinical PTSD (Creamer *et al*., 2003).

2.2.2 Statistical analyses

Initial analyses employed chi-squared tests with post hoc standardised residuals and odds ratios to examine associations between categorical variables and Kruskal–Wallis non-parametric analysis of variance to assess relationships between categorical predictors and continuous IES-R scores. Psychological stress profiles were identified using a two-step cluster analysis based on IES-R intrusion, avoidance and hyperarousal sub-scale scores, with the optimal number of clusters determined via the elbow method and validated using silhouette coefficients. Cluster membership was subsequently profiled using generalised linear models (GLMs) (binomial GLMs) with stepwise variable selection, evaluated using receiver operating characteristic curves and area under the curve (AUC). Variables that improved model performance were then used to develop pruned decision tree models (rpart) with training, validation and test splits to identify key predictors and thresholds for cluster membership.

2.3 Key Findings

2.3.1 *Extreme weather event impacts on mental health and well-being measures of the population*

Several significant relationships were identified between the summed IES-R scores and socio-demographics, EWE exposure and impacts (Tables 2.1 and 2.2). Age group (F (5) = 32.008, $p < 0.001$), employment (F (8) = 28.283, $p < 0.001$), highest level of educational attainment (F (7) = 70.138, $p < 0.001$), settlement type (F (6) = 26.906, $p < 0.001$), annual income (F (6) = 28.485, $p < 0.001$), marital status (F (5) = 14.420, $p = 0.013$), presence of children (F (5) = 15.448, $p = 0.001$) and county (F (26) = 87.259, $p < 0.001$) were all significantly associated with summed IES-R scores. Ageing respondents (age 65+ years) had a significantly lower median total score (6) than the 18–25 (44), 26–34 (43) and 35–49 (33) age groups. Moreover, retired respondents had a significantly lower median total score (6) than respondents looking after the home/family (45), students (44) and self-employed respondents both without employees (42.5) and with employees (42). Respondents with graduate (17.5) and postgraduate (11.5) third-level education had significantly lower total scores than respondents with primary (49), secondary (47) or technical/vocational (43) educational levels. Respondents who were moderately impacted by EWEs had a significantly higher (F (3) = 11.938, $p = 0.008$) total summed IES-R score (44) than respondents who reported being affected "slightly" (30) (Table 2.2). More than half of the respondents reported worsened health (51%); financial difficulties (57.7%); material damage to the household, another type of damage (e.g. motor vehicle damage) or a combination of both (73.2%); and physical EWE-related injury to themselves, family members or both (56.2%) as a direct effect of an EWE (Table 2.2). Moreover, respondents who reported financial difficulties (F (2) = 29.547, $p < 0.001$), material damage (F (4) = 24.176, $p < 0.001$) and previous injuries as a direct effect of an EWE (F (4) = 50.279, $p < 0.001$) exhibited significantly higher total IES-R scores than those who did not. EWE type was also significantly associated with summed IES-R scores (F (10) = 29.226, $p = 0.001$) – respondents who self-reported a storm/gale as a major recent EWE had a significantly lower score (12) than respondents who reported fluvial flooding (42) and heavy rain (40).

2.3.2 *Psychological stress clusters and predictors*

The study identifies four psychological stress clusters: high (33.8%, $n = 154$), moderate (21.2%, $n = 96$), mild (18.9%, $n = 86$) and low (26.3%, $n = 120$) stress. Individuals in the high psychological stress cluster were more likely to have experienced worsened financial and health outcomes post EWE, reside in urban areas and lack postgraduate education (Figure 2.1). Conversely, individuals in the low psychological stress cluster were older (65+), retired, better educated and more likely to reside in suburban settings. Members of the low-risk cluster were more likely to reside in suburban areas. Members of this cluster were also more likely to be older (65+), have higher levels of educational attainment and have yearly household earnings of €60,000 to €80,000. The likelihoods of being retired, being an employee and working in the professional sector were high within this cluster. Members were twice as likely to be married and not live with children. Finally, members were more likely to have no pre-existing health conditions. Members of the low psychological stress cluster were more likely to have experienced a recent storm/gale and less likely to have experienced fluvial flooding. Tangible direct impacts from EWEs were less likely, including being injured, experiencing a worsening financial situation and sustaining property damage.

Table 2.1. Socio-demographic characteristics of survey respondents, delineated by gender, and significant (Kruskal–Wallis) relationships with the summed IES-R scores, with green shading corresponding to a lower summed score and red shading corresponding to a higher summed score

Socio-demographic characteristic		Total population (n=456), n (%)	Male (n=224), n (%)	Female (n=226), n (%)	Total population mean IES-R score (SD)	Total population median IES-R score	p-value
Gender	Female	226 (49.6)	NA	226 (100)	33.9 (1.5)	37	0.16
	Male	224 (49.1)	224 (100)	NA	35.8 (1.5)	40.5	
	Other	4 (0.9)	NA	NA	56.0 (8.3)	61.5	
	Prefer not to say	2 (0.4)	NA	NA	36.5 (10.5)	36.5	
Age group	18–25 years	80 (17.5)	42 (18.8)	38 (16.8)	40.9 (2.2)	44	< 0.001
	26–34 years	202 (44.3)	107 (47.8)	94 (41.6)	38.7 (1.5)	43	
	35–49 years	81 (17.8)	41 (18.3)	38 (16.8)	32.4 (2.7)	33	
	50–64 years	70 (15.4)	23 (10.3)	46 (20.4)	27.0 (2.8)	22	
	65+ years	22 (4.8)	11 (4.9)	10 (4.4)	15.6 (4.0)	6	
	Prefer not to say	1 (0.2)	0 (0)	0 (0)	NA	NA	
Employment	Employee	164 (36)	80 (35.7)	84 (37.2)	31.9 (1.9)	33	< 0.001
	Looking after the home/family	17 (3.7)	2 (0.9)	14 (6.2)	39.4 (5.0)	45	
	Retired from employment	21 (4.6)	10 (4.5)	11 (4.9)	14.9 (3.9)	6	
	Self-employed, with employees	110 (24.1)	61 (27.2)	49 (21.7)	38.4 (1.9)	42	
	Self-employed, without employees	62 (13.6)	36 (16.1)	25 (11.1)	37.5 (2.8)	42.5	
	Student (part- or full-time)	46 (10.1)	21 (9.4)	23 (10.2)	39.4 (3.1)	44	
	Unable to work due to illness/disability	3 (0.7)	3 (1.3)	0 (0)	43.7 (13.1)	52	
	Unemployed	28 (6.1)	10 (4.5)	18 (8)	38.8 (4.1)	41.5	
	Prefer not to say	5 (1.1)	1 (0.4)	2 (0.9)	33.8 (7.3)	26	
Employment sector	Agriculture/fishing/forestry	22 (6.5)	14 (7.9)	8 (5.1)	30.7 (5.1)	31	0.08
	Manual worker	71 (21.1)	40 (22.6)	31 (19.6)	39.8 (2.3)	42	
	Non-manual worker (i.e. retail and service industry)	40 (11.9)	25 (14.1)	15 (9.5)	40.2 (2.9)	45	
	Professional (i.e. office-based roles, engineering and health sectors)	198 (58.9)	97 (54.8)	100 (63.3)	33.2 (1.7)	35	
	Other	5 (1.5)	1 (0.6)	4 (2.5)	18.6 (8.6)	7	
Highest level of educational attainment	No formal education	9 (2)	2 (0.9)	7 (3.1)	NA	NA	< 0.001
	Primary level	53 (11.6)	26 (11.6)	25 (11.1)	47.1 (2.1)	49	
	Secondary level	83 (18.2)	40 (17.9)	42 (18.6)	40.9 (2.4)	47	
	Higher certificate	59 (12.9)	24 (10.7)	35 (15.5)	41.0 (7.7)	54	

Table 2.1. Continued

Socio-demographic characteristic		Total population ($n=456$), n (%)	Male ($n=224$), n (%)	Female ($n=226$), n (%)	Total population mean IES-R score (SD)	Total population median IES-R score	p-value
	Technical or vocational qualification	109 (23.9)	69 (30.8)	40 (17.7)	39.0 (2.0)	43	
	Graduate degree	64 (14)	33 (14.7)	30 (13.3)	22.4 (2.7)	17.5	
	Postgraduate degree	78 (17.1)	30 (13.4)	47 (20.8)	35.0 (2.4)	11.5	
	Prefer not to say	1 (0.2)	0 (0)	0 (0)	NA	NA	
Settlement type	Rural (does not live on farm)	75 (17.6)	37 (17.3)	36 (17.4)	36.4 (2.9)	44	< 0.001
	Rural (lives on farm)	20 (4.7)	10 (4.7)	10 (4.8)	31.3 (6.5)	27	
	Suburban/peri-urban	41 (9.6)	20 (9.3)	21 (10.1)	21.1 (3.4)	9	
	Urban (population < 1000)	111 (26)	65 (30.4)	43 (20.8)	40.7 (1.9)	44	
	Urban (population between 1000 and 20,000)	118 (27.6)	51 (23.8)	66 (31.9)	38.2 (1.9)	43	
	Urban (population > 20,000)	59 (13.8)	30 (14)	29 (14)	33.9 (2.8)	33	
	Prefer not to say	3 (0.7)	1 (0.5)	2 (1)	15.3 (6.3)	19	
Annual income	<€20,000	35 (8.2)	19 (8.9)	15 (7.2)	36.2 (3.6)	38	< 0.001
	€20,000–40,000	166 (38.9)	85 (39.7)	79 (38.2)	41.2 (1.6)	44.5	
	€40,000–60,000	58 (13.6)	27 (12.6)	30 (14.5)	33.6 (3.0)	42	
	€60,000–80,000	37 (8.7)	16 (7.5)	19 (9.2)	21.1 (3.3)	13	
	€80,000–100,000	40 (9.4)	22 (10.3)	18 (8.7)	34.4 (4.0)	42.5	
	>€100,000	67 (15.7)	34 (15.9)	33 (15.9)	37.0 (2.6)	45	
	Prefer not to say	24 (5.6)	11 (5.1)	13 (6.3)	25.3 (4.1)	26.5	
Marital status	Never married	109 (25.1)	59 (27.3)	50 (23.6)	35.6 (2.3)	42	0.013
	Living with partner	93 (21.4)	40 (18.5)	52 (24.5)	38.5 (2.1)	42	
	Married	163 (37.6)	93 (43.1)	68 (32.1)	31.0 (1.8)	29	
	Divorced/separated	55 (12.7)	20 (9.3)	34 (16)	42.8 (2.3)	48	
	Widowed	9 (2.1)	3 (1.4)	5 (2.4)	45.7 (6.9)	52	
	Prefer not to say	5 (1.2)	1 (0.5)	3 (1.4)	29.0 (9.7)	24	
Presence of children	Yes (own children)	113 (26)	71 (32.9)	42 (19.8)	35.7 (2.2)	40	0.001
	Yes (siblings or other relatives)	128 (29.5)	59 (27.3)	67 (31.6)	42.1 (1.7)	45	
	No	181 (41.7)	81 (37.5)	97 (45.8)	31.2 (1.7)	30	
	Prefer not to say	12 (2.8)	5 (2.3)	6 (2.8)	30.2 (6.5)	20.5	

Note that percentages are based on how many people answered the specific question in the survey.

NA, not applicable; SD, standard deviation.

Table 2.2. EWE exposure and impacts reported by survey respondents, delineated by gender, and significant (Kruskal–Wallis) relationships with summed IES-R scores, with green shading corresponding to a lower summed score and red shading corresponding to a higher summed score

EWE exposure or impact		Total population (n=456), n (%)	Male (n=224), n (%)	Female (n=226), n (%)	Total population mean IES-R score (SD)	Total population median IES-R score	p-value
Affected by EWE	Slightly	167 (36.6)	80 (35.7)	85 (37.6)	31.2 (1.8)	30	0.008
	Moderately	224 (49.1)	109 (48.7)	114 (50.4)	38.4 (1.1)	44	
	Quite a bit	51 (11.2)	25 (11.2)	24 (10.6)	30.7 (2.9)	28	
	Extremely	14 (3.1)	10 (4.5)	3 (1.3)	41.3 (6.9)	47.5	
How many EWEs	1 time	102 (22.4)	55 (24.6)	47 (20.8)	39.9 (2.0)	44	0.097
	2–5 times	262 (57.5)	127 (56.7)	131 (58)	32.6 (1.4)	35.5	
	>5 times	91 (20)	41 (18.3)	48 (21.2)	36.3 (2.4)	41	
	Prefer not to say	1 (0.2)	1 (0.4)	0 (0)	NA	NA	
Existing health condition(s)	Yes (physical and mental)	24 (5.3)	11 (4.9)	13 (5.8)	29.4 (5.2)	24	<0.001
	Yes (mental)	119 (26.1)	54 (24.1)	63 (27.9)	38.9 (2.0)	44	
	Yes (physical)	136 (29.8)	79 (35.3)	57 (25.2)	41.5 (1.8)	44.5	
	No	162 (35.5)	75 (33.5)	85 (37.6)	27.6 (1.7)	26.5	
	Prefer not to say	15 (3.3)	5 (2.2)	8 (3.5)	33.9 (5.9)	29	
Health worsened after EWE	Yes	73 (51)	31 (47.7)	41 (53.9)	41.3 (2.5)	46	0.088
	No	56 (39.2)	28 (43.1)	27 (35.5)	32.6 (3.1)	37	
	Prefer not to say	14 (9.8)	6 (9.2)	8 (10.5)	35.3 (6.7)	36	
Financial difficulties after EWE	Yes	263 (57.7)	147 (65.6)	114 (50.4)	40.1 (1.3)	44	<0.001
	No	189 (41.4)	74 (33)	111 (49.1)	27.7 (1.7)	27	
	Prefer not to say	4 (0.9)	3 (1.3)	1 (0.4)	44.3 (16.5)	39	
Material damage(s) after EWE	Yes (household and other)	27 (5.9)	9 (4)	16 (7.1)	32.3 (4.7)	29	<0.001
	Yes (household damage)	106 (23.2)	56 (25)	48 (21.2)	34.5 (2.3)	38.5	
	Yes (other – i.e. motor vehicle damage)	201 (44.1)	108 (48.2)	91 (40.3)	40.1 (1.5)	44	
	No	121 (26.5)	51 (22.8)	70 (31)	27.4 (2.0)	27	
	Prefer not to say	1 (0.2)	0 (0)	1 (0.4)	NA	NA	
Injuries after EWE	Yes (personal and family injury)	79 (17.3)	38 (17)	39 (17.3)	43.2 (2.2)	49	<0.001
	Yes (family member injury)	138 (30.3)	74 (33)	63 (27.9)	41.9 (1.7)	44	
	Yes (personal injury)	39 (8.6)	24 (10.7)	15 (6.6)	37.9 (3.5)	45	
	No	189 (41.4)	82 (36.6)	104 (46)	26.5 (1.6)	23	
	Prefer not to say	11 (2.4)	6 (2.7)	5 (2.2)	25.4 (5.3)	28	

Table 2.2. Continued

EWE exposure or impact		Total population (n=456), n (%)	Male (n=224), n (%)	Female (n=226), n (%)	Total population mean IES-R score (SD)	Total population median IES-R score	p-value
Climate change concern	Not at all concerned	5 (1.5)	1 (0.6)	4 (2.3)	39.6 (5.2)	40	0.075
	Not too concerned	21 (6.2)	12 (7.4)	9 (5.2)	25.6 (4.9)	24	
	Somewhat concerned	130 (38.5)	63 (38.9)	66 (38.4)	30.2 (1.9)	28	
	Very concerned	176 (52.1)	81 (50)	92 (53.5)	35.3 (1.7)	40	
	I don't know	5 (1.5)	4 (2.5)	1 (0.6)	39.4 (9.8)	43	
	Prefer not to say	1 (0.3)	1 (0.6)	0 (0)	NA	NA	
Most recent EWE	< 1 year ago	72 (20.3)	30 (17.8)	40 (22.3)	26.8 (2.7)	20.5	0.179
	2–3 years ago	135 (38.1)	68 (40.2)	67 (37.4)	34.3 (2.1)	37	
	3–5 years ago	99 (28)	54 (32)	43 (24)	35.3 (2.2)	41	
	5–10 years ago	36 (10.2)	14 (8.3)	21 (11.7)	38.5 (3.4)	45	
	> 10 years ago	10 (2.8)	3 (1.8)	6 (3.4)	35.4 (8.1)	37	
	Prefer not to say	2 (0.6)	0 (0)	2 (1.1)	48.0 (9.0)	48	
Recent EWE type	Drought/extreme heat	28 (7.9)	13 (7.7)	14 (7.8)	32.2 (4.9)	29	0.001
	Flooding (coastal/tidal surge)	45 (12.7)	23 (13.6)	21 (11.7)	36.9 (3.7)	42	
	Flooding (river/lake)	82 (23.2)	41 (24.3)	39 (21.8)	38.2 (2.2)	42	
	Heavy rainfall	25 (7.1)	10 (5.9)	15 (8.4)	32.4 (4.7)	40	
	Heavy snowfall/extreme cold	21 (5.9)	9 (5.3)	12 (6.7)	30.1 (4.6)	29	
	Landslide/bog movement or burst	7 (2)	2 (1.2)	5 (2.8)	24.9 (10.6)	56.5	
	Poor air quality (i.e. smog, haze, smoke)	59 (16.7)	35 (20.7)	23 (12.8)	41.7 (2.4)	45	
	Storm/gale	81 (22.9)	30 (17.8)	50 (27.9)	24.0 (2.5)	12	
	Wildfire	3 (0.8)	3 (1.8)	0 (0)	7.0 (2.5)	9	
	Other	2 (0.6)	2 (1.2)	0 (0)	56.5 (31.5)	56.5	
	Prefer not to say	1 (0.3)	1 (0.6)	0 (0)	NA	NA	
General health	Very bad	50 (11.5)	34 (15.7)	16 (7.5)	45.1 (3.2)	52	< 0.001
	Bad	58 (13.4)	22 (10.2)	34 (16)	39.8 (2.2)	43.5	
	Fair	74 (17.1)	38 (17.6)	36 (17)	40.1 (2.8)	50.5	
	Good	136 (31.3)	64 (29.6)	71 (33.5)	31.4 (1.9)	30	
	Very good	112 (25.8)	57 (26.4)	53 (25)	31.1 (2.1)	30	
	Prefer not to say	4 (0.9)	1 (0.5)	2 (0.9)	35.8 (9.1)	35.5	

Note that percentages are based on how many people answered the specific question in the survey.

NA, not applicable; SD, standard deviation.

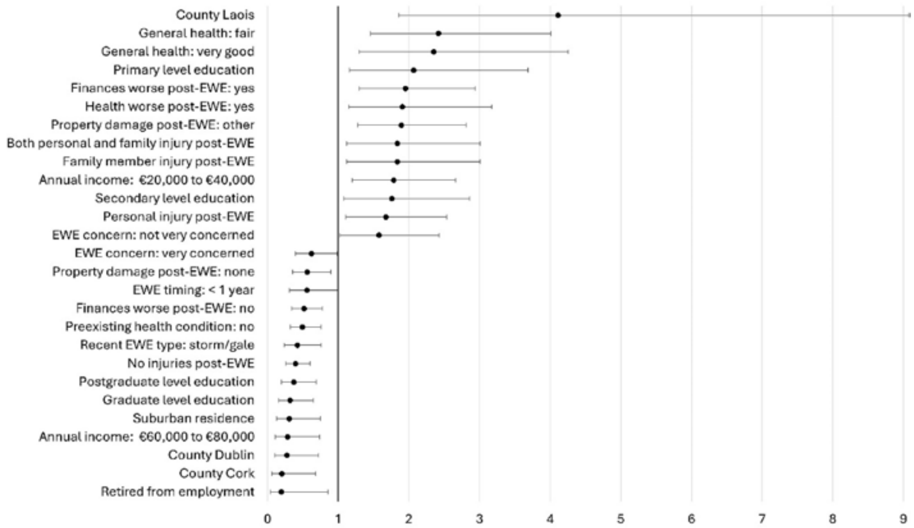

Figure 2.1. Forest plot exhibiting calculated odds ratios and confidence intervals for significantly associated socio-demographics, with EWE exposure and impact variables arranged from most likely to least likely, based on post hoc analysis for cluster 1, "high psychological stress". Source: Reproduced from Batool *et al*., 2025; licensed under CC BY 4.0 (https://creativecommons.org/licenses/by/4.0/).

Overall, the following factors were noted as relevant in terms of risk profile clusters (Batool *et al*., 2025):

- **Age and employment:** elderly respondents displayed lower psychological stress, possibly due to greater resilience or reduced financial obligations. Employment type also influenced stress levels; self-employed individuals with employees showed higher stress than retirees or employed individuals in stable sectors.
- **Geographical disparities:** urban dwellers, particularly those in areas with high population densities, reported higher stress levels than suburban or rural residents. Rural respondents, especially those in farming communities, also faced unique challenges but were less likely to belong to the high-stress cluster.
- **Type and frequency of EWEs:** frequent exposure to EWEs, particularly flooding and storms, was associated with higher stress levels. Respondents who faced multiple EWEs reported cumulative psychological impacts, emphasising the need for repeated and long-term support.
- **Education and awareness:** respondents with higher levels of education were less likely to report severe psychological stress, suggesting that awareness and preparedness might mitigate stress.
- **Climate change perceptions and concerns:** a significant proportion of respondents were "very concerned" about climate change, correlating with heightened stress levels after EWEs.

2.4 Conclusion

Human vulnerability to climate impacts is shaped by a multifaceted interaction of factors, including economic status, geographical location, social conditions and institutional structures (Lynn *et al*., 2011; Hrabok *et al*. 2020). This study builds on existing knowledge by exploring not only the relationship between EWEs and mental health but also the characteristics of populations who are more vulnerable to these impacts. The findings underscore the urgent need for tailored, evidence-based policies to mitigate the mental health impacts of EWEs in Ireland. By prioritising vulnerable populations, enhancing mental health services, and fostering resilience through education and infrastructure improvements, policymakers can reduce the psychological burden of climate change and EWEs.

3 Quantifying the Impacts of Extreme Weather Events on Physical Health

3.1 Rationale

Research indicates that Ireland will be the second most affected European country in terms of the proportion of the national population likely to reside in flood-prone areas by 2100 (Forzieri *et al*., 2017) and is, thus, particularly susceptible to flood-associated health impacts. Compounding this, in Ireland, recent notification rates of VTEC enteritis and cryptosporidiosis, two enteric infections with historically high rates of waterborne transmission (Hunter and Thompson, 2005; Karmali *et al*., 2010), were the highest in the European Union (ECDC, 2019). In Ireland, a high proportion of both infections have been linked with the consumption of, or exposure to, contaminated water (Cummins *et al*., 2010; Hynds *et al*., 2014). However, climate change-induced weather variability, including the intensity and frequency of drought conditions, can also affect the growth, persistence and virulence of pathogens that persist in the environment (Ebi and Bowen, 2016), such as VTEC. Within the sphere of emerging climatic hazards, droughts are frequently considered the least understood, being classified as complex, cumulative, slow-onset (i.e. creeping), persistent and regionally extensive (Pulwarty and Sivakumar, 2014). Drought events serve to deplete available freshwater resources, thus altering hydrodynamic regimes in both surface water- and groundwater-dominated catchments, with environmental and socioeconomic impacts frequently outlasting the drought period (Kayam *et al*., 2009; Mishra and Singh, 2010; Daneshmand *et al*., 2014). Notably, droughts represent a relative, as opposed to absolute, condition (as opposed to flooding) and are, thus, contingent on "normal" (i.e. baseline) and antecedent hydrological conditions (Wilhite *et al*., 2014). Given the climate projections for Ireland, which predict both a decrease in (particularly summer) rainfall and an increase in extreme precipitation, the current study aims to investigate the impact of two past EWEs in Ireland, namely the 2015–2016 winter flood events and the 2018 Europe-wide drought, on the incidence of environmentally associated infectious disease.

3.2 Event 1: The 2015–2016 Winter Flood Events

Winter 2015–2016 was characterised by extremely wet conditions caused by a series of Atlantic storms, resulting in unprecedented, widespread flooding across Ireland and the UK. In addition to the primary, readily observable impacts of the events (e.g. flooding of households and businesses, interruption of transport networks), a significant number (>200) of incidents were reported that pertained to Irish drinking water and wastewater services. From December 2015, several boil water notices were issued, affecting approximately 23,000 people, due to specific concerns around drinking water quality and its potential impact on public health (National Directorate for Fire and Emergency Management, 2016). Despite these warnings and the potentially high-risk scenario, no significant confirmed outbreaks of waterborne infection were officially reported to the Health Service Executive during or immediately after the event. The current study sought to investigate the potential relationship between the winter flood events of 2015–2016 and the incidence of confirmed VTEC enteritis and cryptosporidiosis in Ireland via a retrospective ecological study comprising an ensemble of (geo)statistical techniques.

3.2.1 *Methodology*

Following receipt of ethical approval for this study from the Royal College of Physicians of Ireland Research Ethics Committee (RECSAF_84), access to address-level infectious disease notification data from Ireland's Computerised Infectious Disease Reporting (CIDR) system was granted by the National CIDR Peer Review Committee. Datasets comprised all confirmed cases of sporadic (i.e. non-outbreak) VTEC enteritis reported by regional departments of public health between 1 January 2013 and 31 December 2017. The cryptosporidiosis dataset included all confirmed cases reported from 1 January 2008 to 31 December 2017; cases that occurred prior to January 2008 were not integrated due to a significant outbreak that took place in April 2007, representing a likely source of bias. All individual case notifications for both infections were geographically linked to the centroid of a Central Statistics Office small area (SA), the smallest administrative delineation currently employed in Ireland for national census reporting (18,488 SAs in 2011). Two main periods were identified for the current study:

- the “non-flood” period, corresponding to the total duration of both infection datasets: 2013–2018 for VTEC enteritis (2755 cases) and 2008–2017 for cryptosporidiosis (4509 cases);
- the “flood period”, corresponding to the period between 1 July 2015 and 1 July 2016. This time frame was selected as it represents a complete hydrological year and covers the maximum life expectancy of the longest-lived pathogen, estimated to be a maximum of 5–6 months for *Cryptosporidium* spp. The number of cases of VTEC enteritis and cryptosporidiosis occurring during the flood period were 577 and 607, respectively.

To examine the presence of associations between flood-related hydrometeorology and the occurrence of infection, a national-level case study was performed using three hydrometeorological variables extracted from the Shannon River Basin: cumulative rainfall, river discharge (surface water) and groundwater level. The Shannon River Basin was selected as a representative area due to its central location and geographical significance (15,695 km^2), covering approximately 22% of the country. The river basin was significantly affected by flooding during the 2015–2016 events (National Directorate for Fire and Emergency Management, 2016) and is considered a “hotspot” for both VTEC enteritis and cryptosporidiosis (Boudou *et al.*, 2021). A distinction was made between the Lower Shannon and Upper Shannon sub-basins to assess spatial hydrodynamic variation. For each sub-basin, hydrometeorological data were extracted as follows:

- daily cumulative rainfall from Met Éireann synoptic stations;
- daily mean discharge (cubic metre per second) from Office of Public Works gauging stations;
- daily groundwater level (metres) from the Environmental Protection Agency.

A three-phase ensemble of existing analytical approaches was employed to investigate the presence, magnitude and timing of associations between infection and flooding, in line with the overarching research objective. Seasonal decomposition and space–time scanning were used to detect potential irregularities in the seasonal and spatial distributions of infections during and after the flood period. Subsequently, generalised linear modelling was employed to explore spatial relationships between flood risk exposures, observed flood extent and the incidence of infection at a fine geographical resolution. Finally, exemplar hydrometeorological data (surface water discharge, groundwater level and precipitation) from the Shannon River Basin (the largest river basin in Ireland) were used as flood indicators and modelled in concurrence with infection data via time-series analyses to provide new insights on the timing and “behaviour” of infections within the context of a significant flood event.

3.2.2 Key findings

Seasonal decomposition identified specific seasonal patterns for both infections (Figure 3.1). With respect to seasonal variations, VTEC infection exhibits high incidence during mid/late summer (peaking in July), with a second peak in September, while cryptosporidiosis incidence is highest during spring (March to May, peaking in April). Both infections displayed a general (cumulative) increase trend over their respective study periods. Notably, both infections exhibited a marked residual (i.e. seasonal trend excluded) peak during April 2016, accounting for +23 observed residual cases for VTEC enteritis and +57 observed residual cases for cryptosporidiosis. Other secondary residual peaks were identified, particularly during June–July 2016 for VTEC enteritis.

Space–time scanning of VTEC cases identified three significant ($p < 0.05$) clusters (83 cases in total) during the flood period, all of which intersected (25–35%) with the Shannon River Basin catchment area. The two largest clusters, 40 and 29 cases, were identified east and south-west of Limerick city, respectively, and occurred between April and June 2016 (Figure 3.2). A third cluster was observed further north (County Cavan) in September 2015 (14 cases). Eight significant space–time clusters of cryptosporidiosis were identified during the flood period, accounting

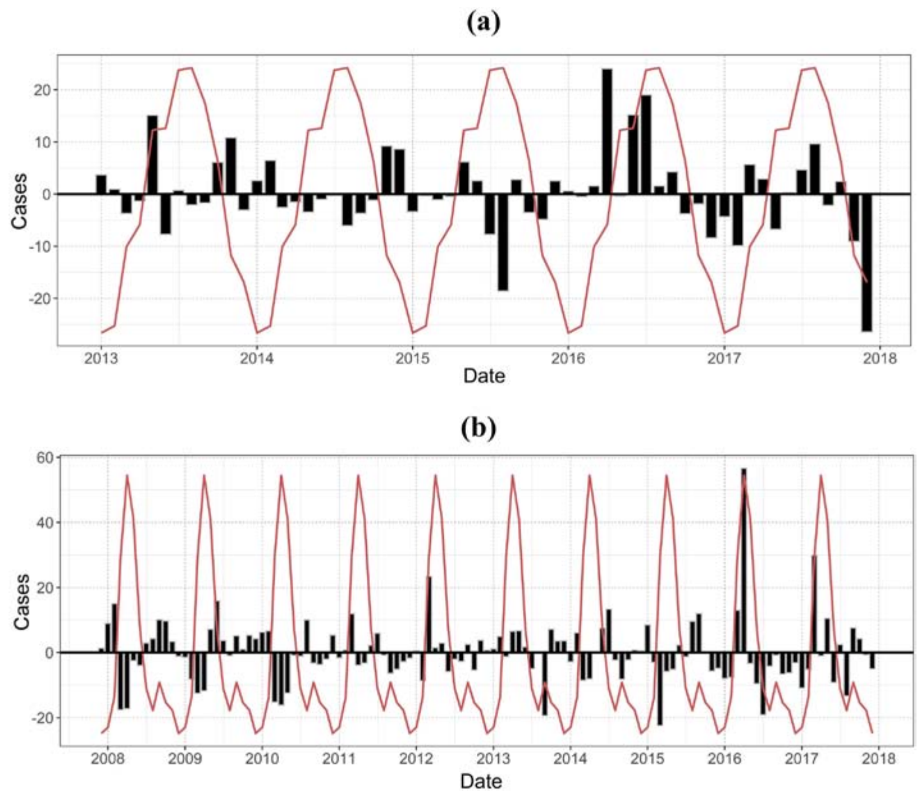

Figure 3.1. Residuals (in black) and seasonal variations (in red) obtained from Loess seasonal decomposition for (a) VTEC enteritis (2013–2018) and (b) cryptosporidiosis (2008–2018).

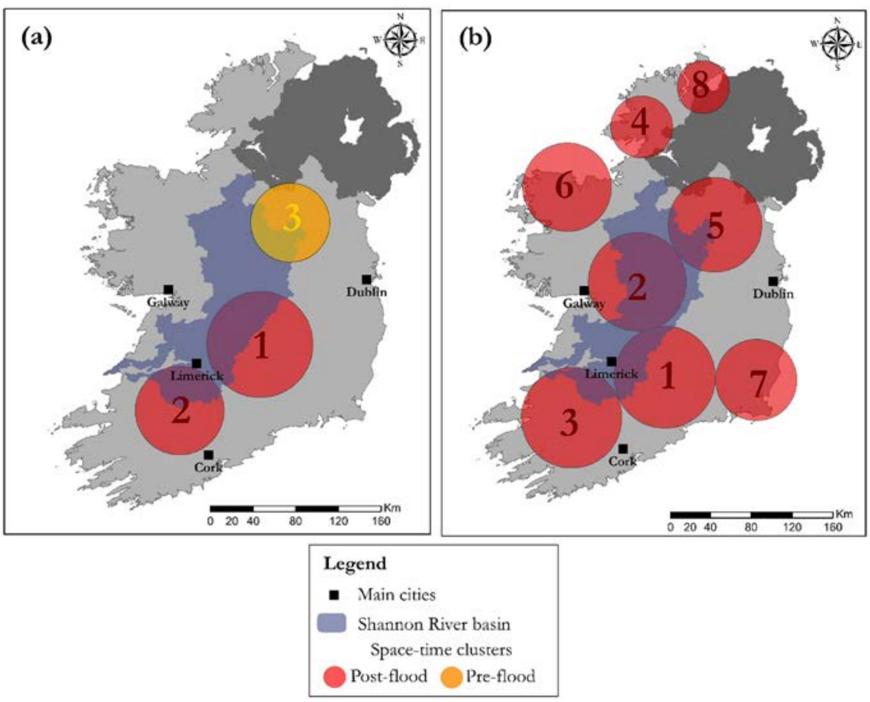

Figure 3.2. Space–time clusters from July 2015 to July 2016 for (a) VTEC enteritis and (b) cryptosporidiosis, with the Shannon River Basin indicated in blue.

for 238 cases (Figure 3.2). The spatial distribution of these clusters was relatively widespread across the country, with four clusters intersecting with the Shannon River Basin. The temporal distribution of clusters was from March to May 2016 for clusters 1, 2, 3 and 7 (south midlands and south) and from April to June 2016 for clusters 4, 5, 6 and 8 (north midlands and north).

3.2.3 Flood hydrometeorology: time-series analyses

Results of optimised time-series models for VTEC enteritis indicate relatively similar responses between both sub-basins, highlighting two significant primary associational periods (i.e. lags) (Ljung–Box $p > 0.05$) from weeks 12 to 14 and 17 to 19 (indicated in red in Figure 3.3). Higher levels of association were observed in the Lower Shannon basin, with the maximum *p*-values calculated for surface water discharge being significantly higher than those obtained for rainfall and groundwater level within both sub-basins. The maximum associations found for each variable were as follows:

- **Rainfall:** week 12 ($p = 0.062$), Upper Shannon; week 13 ($p = 0.071$), Lower Shannon.
- **Surface water:** week 18 ($p = 0.072$), Upper Shannon; week 19 ($p = 0.105$), Lower Shannon.
- **Groundwater level:** week 12 ($p = 0.061$), Upper Shannon; week 12 ($p = 0.06$), Lower Shannon.

Likewise, two specific periods of association were found between antecedent hydrometeorological variables and the occurrence of excess cryptosporidiosis cases, namely from week 8 to 10 and week 16 to 21 (Figure 3.4). Levels of association for cryptosporidiosis were higher in the Upper Shannon sub-basin than the Lower Shannon sub-basin and were significantly higher than those found for VTEC enteritis. The best fit weekly lags found by calculating the *p*-values of Ljung–Box tests appear identical between both sub-basins, as follows:

- **Rainfall:** week 19 ($p = 0.274$, Lower Shannon; $p = 0.522$, Upper Shannon).
- **Surface water:** week 18 ($p = 0.371$, Lower Shannon; $p = 0.577$, Upper Shannon).
- **Groundwater level:** week 18 ($p = 0.395$, Lower Shannon; $p = 0.424$, Upper Shannon).

3.2.4 Conclusion

This study provides robust evidence linking the 2015–2016 winter flood events in Ireland to elevated incidence of gastroenteric infections (VTEC enteritis and cryptosporidiosis). Highlighting the interplay between hydrometeorology and infection dynamics underscores the need for multidisciplinary approaches

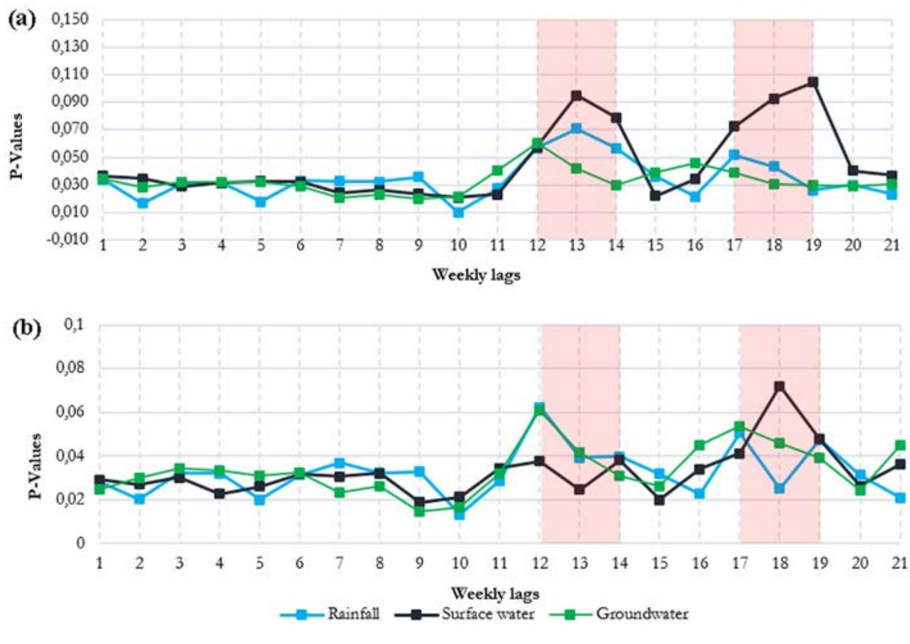

Figure 3.3. Autoregressive integrated moving average Ljung–Box test results for VTEC enteritis in (a) the Lower Shannon sub-basin and (b) the Upper Shannon sub-basin.

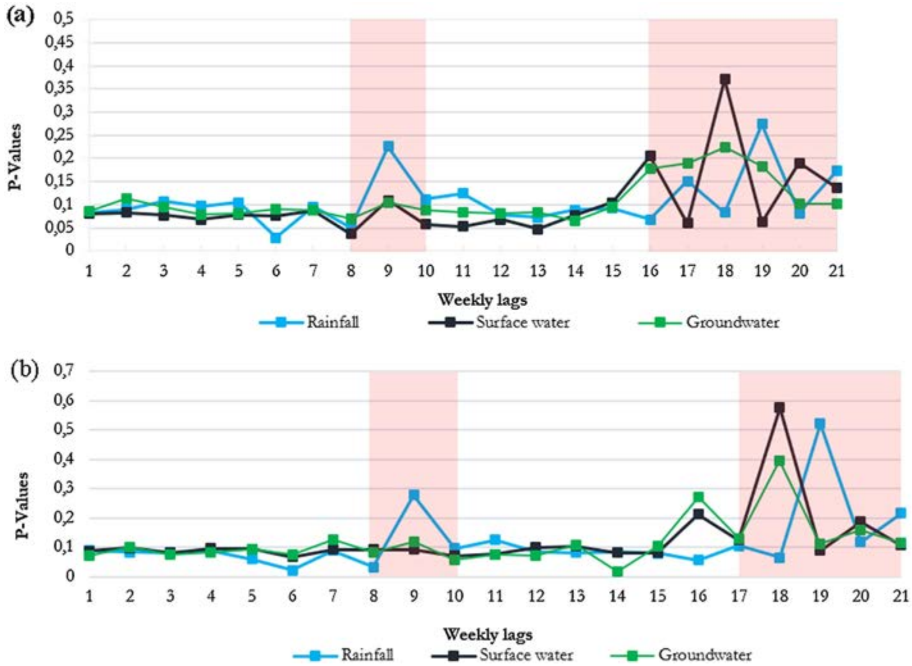

Figure 3.4. Autoregressive integrated moving average Ljung–Box test results for cryptosporidiosis in (a) the Lower Shannon sub-basin and (b) the Upper Shannon sub-basin.

to safeguard public health in the face of the increasing frequency of EWEs. The findings offer a foundation for developing evidence-based policies and interventions to mitigate the health impacts of climate change.

3.3 Event 2: The 2018 European Summer Heatwave

The 2018 European summer heatwave brought record-breaking temperatures and drought conditions to much of Europe, including Ireland. Beginning in May, dry weather patterns became progressively more pronounced throughout the country, culminating in an official declaration of the commencement of the 2018 summer drought on 22 May (Augustenborg *et al.*, 2022). Dry conditions persisted until 28 July, marking the most severe hydrological drought observed in Ireland since 1981. During the drought period, the entire country experienced conditions ranging from "severely" dry to "extremely" dry according to the Standardized Precipitation Index (Falzoi *et al.*, 2019). The 2018 summer drought, which garnered significant media attention (Antwi *et al.*, 2022; Augustenborg *et al.*, 2022), had far-reaching effects on agriculture, water supply and water quality (Falzoi *et al.*, 2019; Mellander and Jordan, 2021; O'Dwyer *et al.*, 2021). This study examines the public health impacts of this heatwave by analysing the incidence of VTEC enteritis. VTEC enteritis was selected as the outcome of interest because it represents a significant and recurrent gastrointestinal disease burden in Ireland and is strongly associated with private groundwater supplies, which are particularly vulnerable to contamination during drought and heatwave conditions, when reduced dilution and increased reliance on private wells elevate infection risk. The research quantifies excess case notifications during the heatwave period and explores the demographic, spatial and temporal patterns of infection. By understanding these relationships, the study provides insights into the health implications of drought conditions in temperate maritime climates such as Ireland's.

3.3.1 Methodology

To examine the effects of the 2018 summer drought on sporadic (i.e. non-outbreak) cases of infection, only georeferenced primary cases of infection were included for statistical analysis. Overall, 6277 cases of VTEC (84.4% of the total) reported from January 2013 to December 2022 were successfully georeferenced. Interrupted time-series analysis modelling was used to examine the (potential) impact of the 2018 summer drought on VTEC incidence rates via the "itsa.model" function in RStudio ("its.analysis"

package, version 1.6.0). This function performs a type-2 sum of squares analysis of covariance on a lagged dependent variable model, enabling statistical evaluation of mean differences between specific time periods (Boudou *et al.*, 2025). The model produces several outputs, including a trimmed median *F*-value, used to derive bootstrapped *p*-values for both the non-lagged and lagged dependent variables. The median slope was also employed to assess the interruption effect during and after the 2018 summer heatwave event. In the context of the present study, bootstrapped models with 250 iterations and a significance level of $\alpha = 0.05$ were employed. To examine precisely the potential hotspot distribution of the infection during the 2018 summer drought event, spatial autocorrelation using the Getis–Ord G_{i*} geostatistical tool in ArcGIS (version 10.6) was undertaken. The Getis–Ord G_{i*} statistic, originally introduced by Getis and Ord (1992), enables the detection of spatial clusters distinguished by notably low or high degrees of correlation.
A simplified representation of the G_{i*} statistical formula can be expressed as follows:

$$G_{i^*} = \frac{\sum_{j=1}^{n} W_{ij} X_j}{\sum_{j=1}^{n} X_j} \tag{3.1}$$

In this context, "G_i" denotes the spatial interdependence of an incident "i" with respect to all occurrences "n". "X_j" stands for the value of variable X at the location of the incident "j" in relation to all occurrences "n". Lastly, "W_{ij}" signifies the spatial connection or weighting value between the incidents "i" and "j" (Songchitruksa and Zeng, 2010). This operation was performed for the entire time series of both infections (i.e. incidence rate per 100,000 was used to take into account the population density across SAs) and for the 2018 summer drought period (i.e. 22 May to 28 July 2018).

3.3.2 Key findings

Infection time series

The seasonally adjusted time series of primary cases of VTEC (2013–2020) is presented in Figure 3.5. As shown, the highest peak of VTEC enteritis notification was recorded in August 2020, with approximately +43 cases. June 2018, during the delineated drought period, registered the second-highest peak of the study period, with approximately +27 cases reported during the last week of the month.

The distribution of infection cases for VTEC enteritis for the entire time series (pre- and post-drought period) and the drought period (22 May to 28 July 2018) is presented in Table 3.1. Overall, 201 cases of VTEC (3.2%) were reported during the drought period. Gender delineations revealed that a higher proportion of VTEC cases occurred among men during the drought period (51.7%), while a higher number of cases were associated with women across the rest of the time series. With respect to age, higher percentages of VTEC cases were noted among the <5 years cohort during the drought period. Conversely, slightly higher incidence rates were reported among the 21–45 (VTEC: +3.3%) and 65+ age cohorts (VTEC: +1.1%). An increase in rural VTEC cases was observed during the drought period (+2.2%). Interestingly, the proportion of VTEC enteritis attributed to the O26 serotype was significantly higher during the

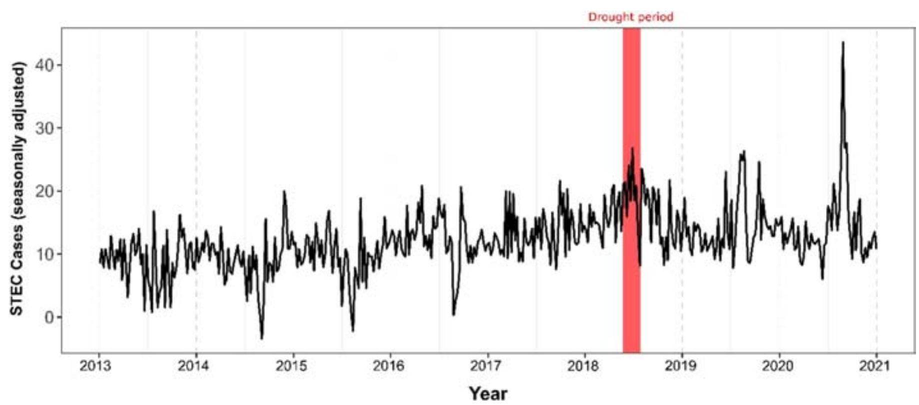

Figure 3.5. Seasonally adjusted time series of VTEC/Shiga toxin-producing *E. coli* (STEC) incidence in Ireland (2013–2020).

Table 3.1. Infection time-series characteristics including case gender, age group, settlement type, geographical location and VTEC serotype

Characteristic		VTEC enteritis cases (n = 6277), n (%)	
		Pre-/post-drought period	Drought period
Total		6076 (96.8)	201 (3.2)
Gender	Female	3182 (52.4)	97 (48.3)
	Male	2894 (47.6)	104 (51.7)
Age group	< 5	2163 (35.6)	63 (31.3)
	5–20	966 (15.9)	34 (16.9)
	21–45	1002 (16.5)	36 (17.9)
	45–65	819 (13.5)	24 (11.9)
	65+	1125 (18.5)	44 (21.9)
Settlement type	Rural	2315 (38.1)	81 (40.3)
	Urban	2258 (37.2)	74 (36.8)
	Commuter	1503 (24.7)	46 (22.9)
Geographical location	East	2117 (34.8)	75 (37.3)
	North	708 (11.7)	28 (13.9)
	West	1641 (27)	54 (26.9)
	South	1610 (26.5)	44 (21.9)
Serotype	O26	1522 (25)	62 (30.8)
	O157	1127 (18.5)	32 (15.9)

drought period, with 30.8% of total cases, than outside the drought period, with 24.2% of total cases.

Spatial autocorrelation

The spatial autocorrelation (Figure 3.6) analysis for VTEC enteritis showed a clear redistribution of hotspots during the 2018 heatwave. In the pre- and post-heatwave period, VTEC hotspots were widely distributed across a predominantly rural and agricultural corridor extending from County Cork in the south to County Monaghan in the north, while cold spots were concentrated in northern counties and along the east coast, including the Dublin metropolitan area. During the heatwave this pattern shifted, with new VTEC hotspots emerging in northern regions (notably in County Donegal), and with the east coast, apart from Dublin, largely losing its cold spot status, indicating a heatwave-related spatial expansion of elevated VTEC infection risk into areas not typically associated with high incidence.

While the interpretation of the epidemiology of enteric pathogens is complicated by the complex interplays between climatic and other environmental variables (Sobsey *et al*., 2006), the 2018 summer drought period was shown to coincide with the second-highest seasonally adjusted peak of VTEC infections for that year. A statistical association was noted between high VTEC cases and categorically rural areas, which is consistent with infection via a variety of well-known routes of transmission, primarily water sources (Hynds *et al*., 2014; Óhaiseadha *et al*., 2017; Chique *et al*., 2021b). However, it must be noted that heat-related behaviours are also likely to have played a role, with direct contact with animals and consumption of poorly cooked meat also being key risk factors. In Ireland, VTEC cases in rural areas have been consistently linked with the utilisation of private (groundwater) water sources (Óhaiseadha *et al*., 2017), with microbiological contamination (*E. coli*) of groundwater reported in 66.7% of monitoring wells (n = 132) over a 10-year period in Ireland (Andrade *et al*., 2022). However, research by O'Dwyer *et al*. (2021) during the 2018 drought showed a decrease in private well contamination during the extended dry period, with increases in contamination resuming (and being amplified) following rainfall events post drought. This may suggest that the highest peak of VTEC infections, in August 2020, which is uncharacteristically late (the peak is routinely May to June), may have been fuelled by enhanced microbial mobilisation of the pathogen to groundwater supplies following resumption of "normal" hydrogeological conditions. Therefore, the findings are highly relevant for groundwater consumers and public health authorities, particularly given the general lack of treatment of groundwater supplies and the potential health risks associated with consumption of contaminated groundwater.

3.3.3 Conclusion

The 2018 European summer heatwave significantly impacted bacterial gastroenteritis incidence in Ireland, underscoring the vulnerability of temperate maritime climates to EWEs. Findings highlight the urgent need for targeted public health interventions and climate adaptation measures to mitigate future risks. By addressing both immediate and delayed health effects, policymakers can enhance resilience to the growing threat of climate-driven infectious diseases. Overall, this research demonstrates that hydrological drought conditions can directly and indirectly increase the transmission of pathogens like VTEC. While food-borne and waterborne sources are considered the

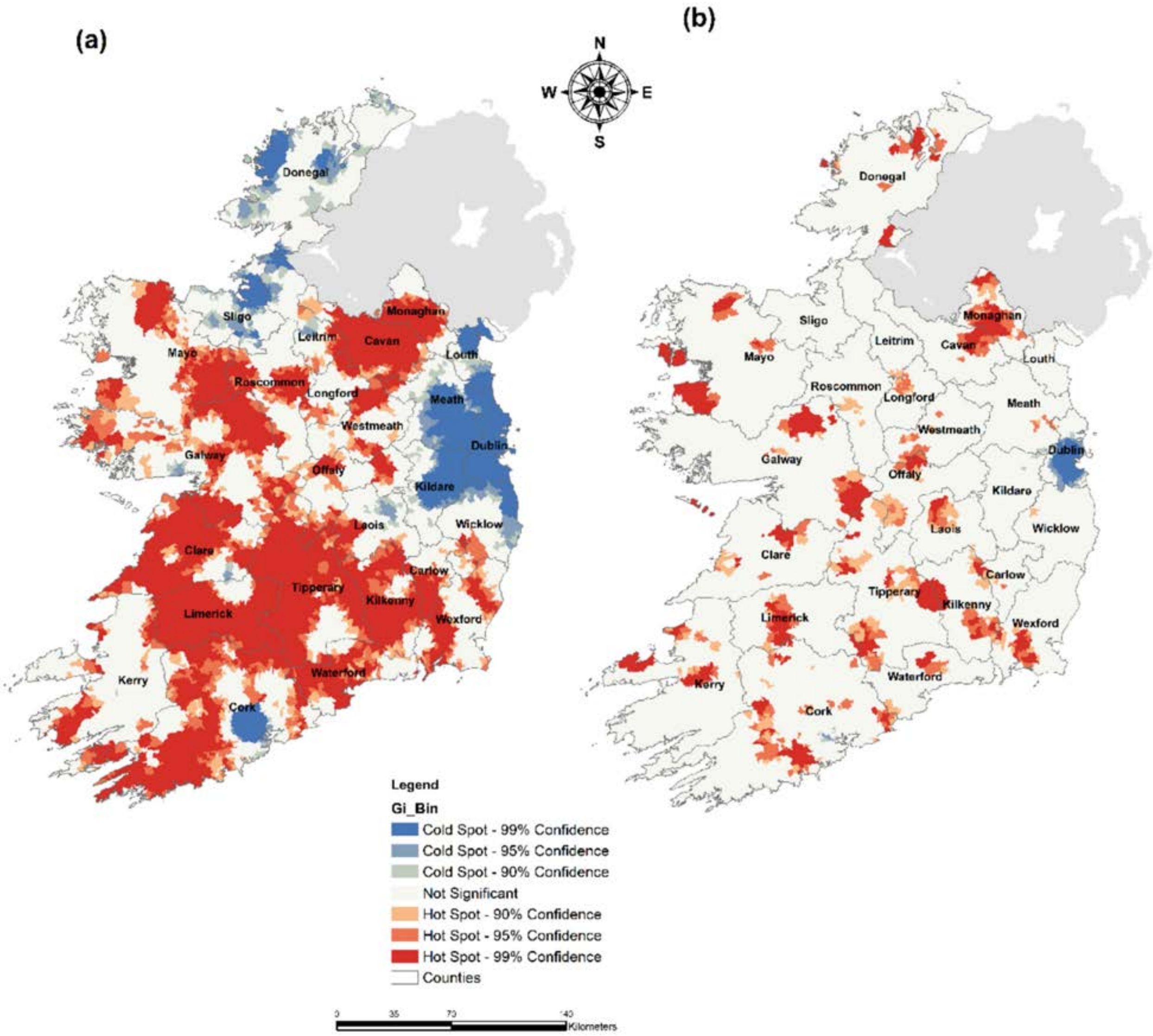

Figure 3.6. Spatial hotspots and cold spots of VTEC incidence rate per 100,000 people (Getis–Ord G_{i*}) in the (a) pre- and post-heatwave period and (b) heatwave period.

major transmission pathways for VTEC, the findings reported here suggest that meteorological variability may play a significant role in contamination events, warranting further investigation. In light of the world's changing climate, further understanding of the complex relationship between meteorological and climatological events and environmentally associated infections is essential for the development of targeted public health strategies and the implementation of necessary climate change adaptation measures.

4 Projecting Climate-related Health Risks

4.1 Rationale

Climate change is expected to have significant implications for public health in Ireland, particularly through its impact on waterborne diseases, as shown in Chapter 3. Rising temperatures, increased rainfall variability and more frequent EWEs such as storms and flooding are likely to affect water quality and the prevalence of waterborne pathogens. Heavy rainfall and flooding can overwhelm wastewater treatment systems, leading to contamination of drinking water sources with pathogens such as *Cryptosporidium* and *E. coli*, increasing the risk of gastrointestinal illnesses and outbreaks. Additionally, changes in precipitation patterns could lead to prolonged periods of drought, reducing water availability and increasing the concentration of pollutants in water supplies. Vulnerable populations, including children, the elderly and people with weakened immune systems, are particularly at risk, highlighting the need for proactive public health measures. Investigating these future risks is essential to strengthen Ireland's water quality monitoring, improve infrastructure resilience and develop climate-adaptive public health policies. By assessing these threats now, Ireland can implement strategies to safeguard public health and ensure the continued safety of its water resources in a changing climate. The study highlights the significant impact that climate change could have on the prevalence of two enteric infections in Ireland, namely VTEC and cryptosporidiosis, for which Ireland has a persistently high burden of disease. Using space–time scanning, statistical modelling and Monte Carlo simulations, the research identified clear associations between climate factors – particularly temperature and rainfall – and the distribution of these infections.

4.2 Methodology

Infection data comprised irreversibly anonymised cases of laboratory-confirmed VTEC enteritis and cryptosporidiosis reported in Ireland and collated through the national CIDR database. Cases were georeferenced, as described previously. Weekly seasonal adjustment of developed time series (trend and residuals of seasonally decomposed time series) was undertaken for both climate and infection variables (incidence rate per 100,000 population). Climate variables were lagged from 1 to 20 weeks to account for likely delayed associations. Infection hotspots were identified and used to construct space–time cluster frequency maps (Boudou *et al*., 2021; Cleary *et al*. 2021), with Monte Carlo simulations used to simulate the effects of weekly mean temperature and rainfall changes on space–time cluster frequency.

4.3 Key Findings

The analysis showed that climate change is likely to alter the patterns of infectious disease transmission, particularly for waterborne pathogens. The latest climate projections for Ireland suggest an increase in annual temperatures of 1–1.6°C by 2100 (Nolan, 2025), with seasonal peaks of +2.6°C in summer and +3.1°C in winter (based on Shared Socioeconomic Pathway 1-2.6). While total annual rainfall is expected to decrease, rainfall events will become more intense and sporadic, leading to more frequent episodes of flooding and drought. These changes are likely to create conditions that favour the persistence and transmission of waterborne pathogens, increasing the risk of disease outbreaks. Analysis of past infection data (2011–2018) revealed seasonal peaks for each disease, with VTEC enteritis cases peaking in summer and autumn (July and September) and cryptosporidiosis cases peaking in spring (April). Space–time scanning identified persistent disease clusters, confirming that certain regions in Ireland consistently experience higher infection rates (Figure 4.1).

Statistical modelling using GLMs confirmed that temperature and rainfall were key predictors of disease incidence for VTEC enteritis and cryptosporidiosis (Table 4.1). For cryptosporidiosis, which is exclusively waterborne, rainfall played a dominant role in driving infection rates. An increase in winter rainfall, which is projected to become more intense in Ireland, is likely to create conditions for increased run-off contamination to water sources, facilitating outbreaks. VTEC infections were influenced by both temperature and rainfall, suggesting that warming conditions could

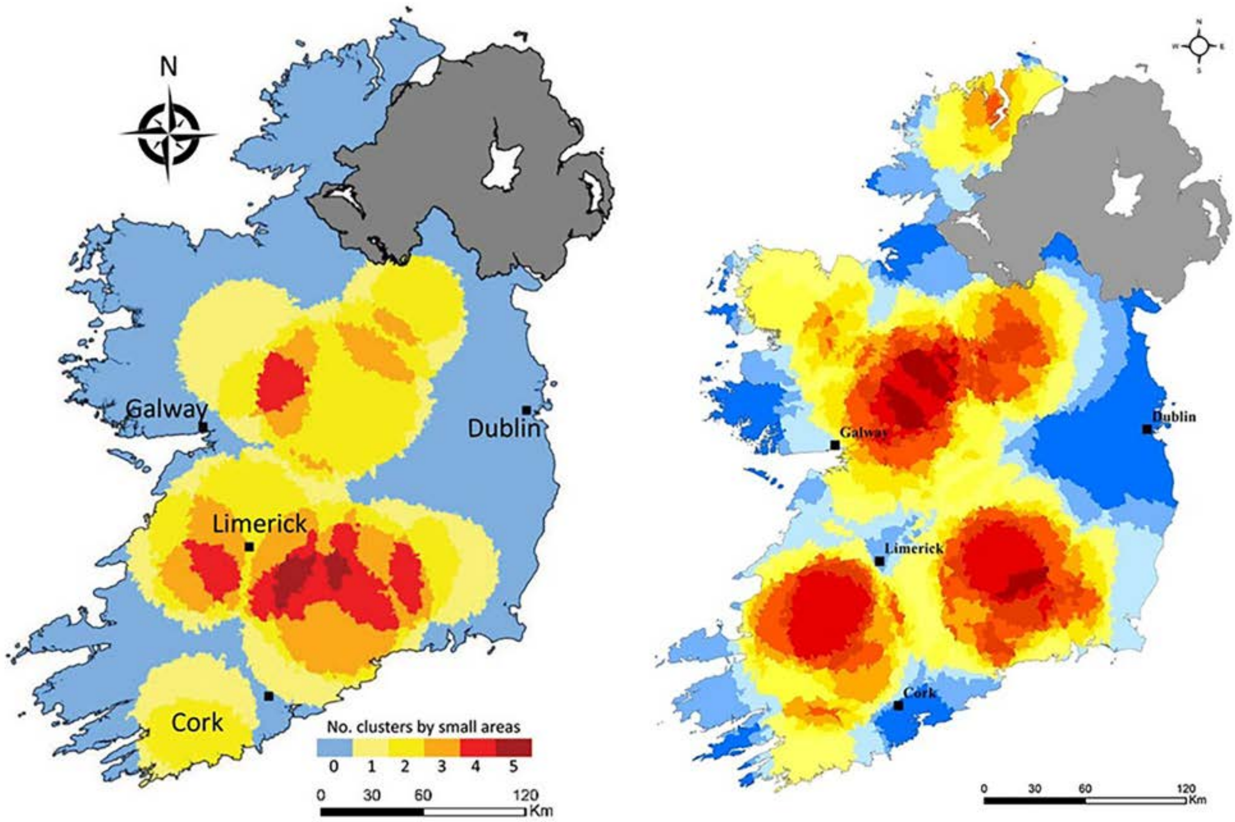

Figure 4.1. Disease clusters identified via space–time scanning for VTEC (left) and cryptosporidiosis (right).

Table 4.1. AUC, *p*-values and odds ratios associated with rainfall and temperature for VTEC enteritis and cryptosporidiosis using generalised linear modelling

		Temperature		Rainfall	
Disease	AUC	*p*-value	Odds ratio	*p*-value	Odds ratio
VTEC enteritis	0.91	<0.001	6.82	<0.001	1.025
Cryptosporidiosis	0.95	<0.001	2.66	<0.001	1.09

enhance bacterial survival and transmission in water systems, while heavy rainfall events could increase contamination from agricultural run-off.

Monte Carlo simulations demonstrated that climate change is likely to significantly increase the number of areas experiencing incidence of these diseases. Under a scenario where temperatures rise by 2°C, the number of areas reporting VTEC infections could increase by 219% (Figure 4.2). Similarly, an increase of 20 mm in rainfall is projected to lead to a 127% rise in cryptosporidiosis clusters and a 117% increase in VTEC enteritis clusters (Figure 4.3).

4.4 Conclusion

Overall, the study provides compelling evidence that climate change will significantly affect the spatial and seasonal distribution of infectious diseases in Ireland, particularly those that are waterborne. As temperatures rise and EWEs become more frequent, public health planning must incorporate climate risk assessments to prevent and mitigate the spread of these infections. By taking proactive measures now, Ireland can strengthen its resilience to climate-driven disease incidence and protect public health in the future. These findings highlight the urgent need for

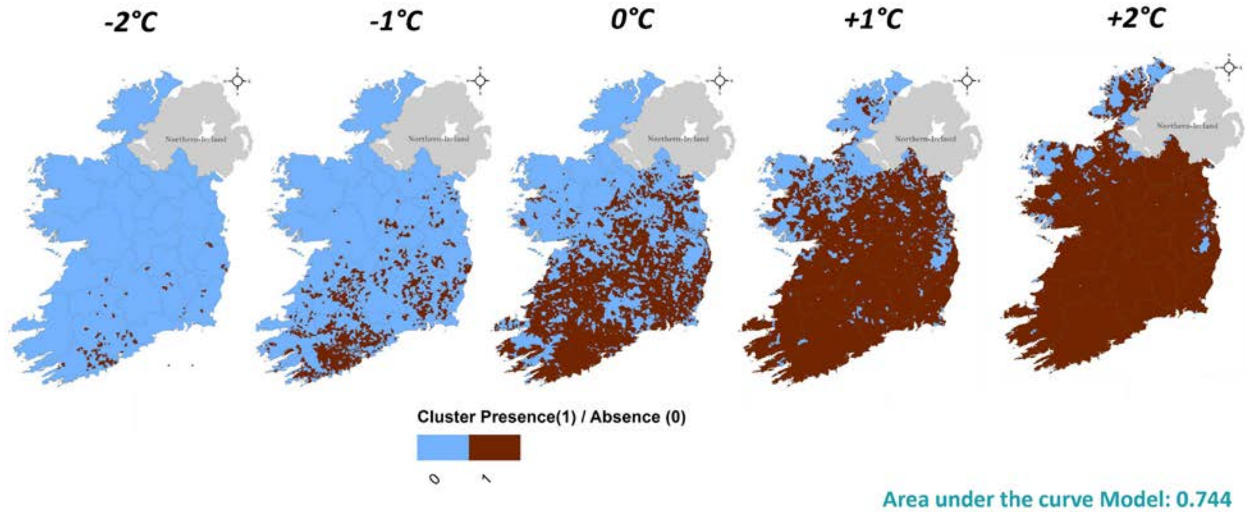

Figure 4.2. Monte Carlo simulation results for VTEC incidence clusters across varying temperature scenarios (–2°C to +2°C).

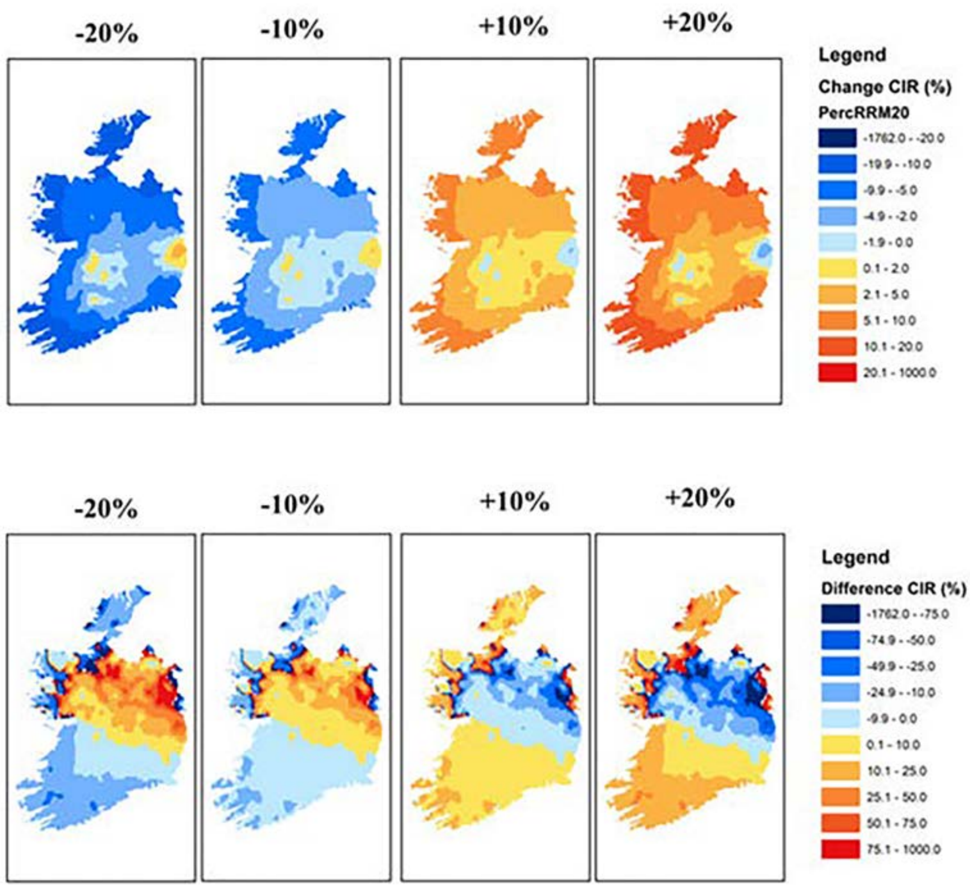

Figure 4.3. Monte Carlo simulation results for VTEC enteritis (top) and cryptosporidiosis (bottom) under varying rainfall scenarios. CIR, crude incidence rate; PercRRM20, percentage relative rainfall (monthly) totals from –20% to +20%.

climate-adaptive public health strategies in Ireland. The projected increase in waterborne disease outbreaks calls for enhanced water quality monitoring, improved wastewater treatment infrastructure and better flood risk management. Given that VTEC enteritis and cryptosporidiosis are linked to both temperature and rainfall, it is essential to implement early warning systems to anticipate periods of high disease risk, particularly following EWEs. Additionally, agricultural run-off management will be critical in reducing contamination risks, especially in rural areas where livestock density is high.

5 Conclusions and Recommendations for Evidence-based Policy

The CRISIS project concludes that climate change is already impacting and will continue to significantly affect public health in Ireland, particularly through waterborne diseases, EWEs and mental health stressors. Key findings reveal that EWEs such as floods, storms and heatwaves exacerbate mental stress, particularly among younger, urban-dwelling and socioeconomically disadvantaged populations. The study identifies four psychological stress clusters, with higher stress linked to financial difficulties, property damage from EWEs and lower educational attainment. Moreover, the CRISIS project identifies VTEC and *Cryptosporidium* as highly sensitive to climate variability, with temperature increases and extreme rainfall events leading to higher infection risks. Climate projections indicate that rising temperatures and more frequent heavy rainfall will exacerbate disease incidence, particularly in rural areas where agricultural run-off can contaminate water sources. The report highlights the urgent need for adaptive public health strategies to mitigate these risks. This includes enhanced disease surveillance, improved water infrastructure resilience and early warning systems to anticipate climate-related incidence. The study also stresses the importance of interdisciplinary collaboration between public health officials, environmental scientists and policymakers to ensure that climate adaptation measures are science-driven and effective. In summary, the CRISIS project calls for proactive, evidence-based policies to protect public health from the growing risks of climate change. By strengthening public health preparedness, investing in climate-resilient infrastructure and improving multi-sectoral cooperation, Ireland can reduce the long-term burden of climate-driven health impacts and build more resilient communities. The policy recommendations presented below were derived through a structured synthesis of (i) the empirical findings of this study, (ii) complementary quantitative and qualitative outputs from the CRISIS project and (iii) established evidence from the peer-reviewed literature on EWEs, mental health and environmental health risk. Recommendations were iteratively developed by the research team to directly address the vulnerabilities and transmission pathways identified in the analyses (e.g. psychological stress clustering, spatial redistribution of infection risk, and heightened exposure among rural and private well-reliant populations). While not produced through a formal consensus method (e.g. Delphi process), the recommendations reflect evidence-informed interpretation rather than opinion, with stronger emphasis placed on the areas most directly supported by the study findings and CRISIS project deliverables:

- **Integrated mental health and disaster response framework:** mental health services should be embedded in disaster response plans, with first responders trained in psychological first aid. Moreover, mobile mental health units should be established for vulnerable communities to provide rapid support in affected areas.
- **Policy monitoring and evaluation:** the effectiveness of mental health and disaster mitigation programmes should be regularly assessed and amended. It is recommended that follow-up studies are conducted to evaluate long-term psychological impacts and adjust interventions accordingly.
- **Cross-sector collaboration:** stakeholders from the public health, urban/rural planning, education and environmental sectors should actively and routinely engage to develop holistic solutions that produce tangible and measurable impacts. Moreover, international collaborations to share best practices and adapt successful models from other regions should be encouraged.
- **Investment in data and research:** data collection on mental health outcomes post EWEs is urgently required to refine predictive models and develop resilience-building strategies at the local level. Furthermore, investment in longitudinal studies to track the evolving impacts of climate change on mental health is required.

- **Surveillance and risk management:** real-time monitoring systems for pathogens in flood-affected areas should be developed to protect human health, enhancing public health surveillance to detect atypical infection peaks.
- **Infrastructure improvements:** this study's findings further strengthen the need for improved wastewater management and flood defences in vulnerable areas. In particular, safe drinking water practices, particularly for private well owners, need to be fostered and promoted at a national scale.
- **Public health campaigns:** safe food handling practices, particularly during heatwaves, need to be incorporated into a national, proactive public health campaign. Importantly, education on drinking water safety, especially in rural areas reliant on private wells, is urgently needed. It is recommended that a national sampling regime for private wells be established to assess the risk at the local level.

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Abbreviations

AUC	Area under the curve
CIDR	Computerised Infectious Disease Reporting
CRISIS	Climate Change in the Republic of Ireland: Societal Impacts and Solutions
EWE	Extreme weather event
GLM	Generalised linear model
IES-R	Impact of Event Scale – Revised
PTSD	Post-traumatic stress disorder
SA	Small area
VTEC	Verotoxigenic *Escherichia coli*

An Ghníomhaireacht Um Chaomhnú Comhshaoil

Tá an GCC freagrach as an gcomhshaol a chosaint agus a fheabhsú, mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ar thionchar díobhálach na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialáil: Rialáil agus córais chomhlíonta comhshaoil éifeachtacha a chur i bhfeidhm, chun dea-thorthaí comhshaoil a bhaint amach agus díriú orthu siúd nach mbíonn ag cloí leo.

Eolas: Sonraí, eolas agus measúnú ardchaighdeáin, spriocdhírithe agus tráthúil a chur ar fáil i leith an chomhshaoil chun bonn eolais a chur faoin gcinnteoireacht.

Abhcóideacht: Ag obair le daoine eile ar son timpeallachta glaine, táirgiúla agus dea-chosanta agus ar son cleachtas inbhuanaithe i dtaobh an chomhshaoil.

I measc ár gcuid freagrachtaí tá:

Ceadúnú

> Gníomhaíochtaí tionscail, dramhaíola agus stórála peitril ar scála mór;
> Sceitheadh fuíolluisce uirbigh;
> Úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe;
> Foinsí radaíochta ianúcháin;
> Astaíochtaí gás ceaptha teasa ó thionscal agus ón eitlíocht trí Scéim an AE um Thrádáil Astaíochtaí.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil

> Iniúchadh agus cigireacht ar shaoráidí a bhfuil ceadúnas acu ón GCC;
> Cur i bhfeidhm an dea-chleachtais a stiúradh i ngníomhaíochtaí agus i saoráidí rialáilte;
> Maoirseacht a dhéanamh ar fhreagrachtaí an údaráis áitiúil as cosaint an chomhshaoil;
> Caighdeán an uisce óil phoiblí a rialáil agus údaruithe um sceitheadh fuíolluisce uirbigh a fhorfheidhmiú
> Caighdeán an uisce óil phoiblí agus phríobháidigh a mheasúnú agus tuairisciú air;
> Comhordú a dhéanamh ar líonra d'eagraíochtaí seirbhíse poiblí chun tacú le gníomhú i gcoinne coireachta comhshaoil;
> An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Dramhaíola agus Ceimiceáin sa Chomhshaol

> Rialacháin dramhaíola a chur i bhfeidhm agus a fhorfheidhmiú lena n-áirítear saincheisteanna forfheidhmithe náisiúnta;
> Staitisticí dramhaíola náisiúnta a ullmhú agus a fhoilsiú chomh maith leis an bPlean Náisiúnta um Bainistíocht Dramhaíola Guaisí;
> An Clár Náisiúnta um Chosc Dramhaíola a fhorbairt agus a chur i bhfeidhm;
> Reachtaíocht ar rialú ceimiceán sa timpeallacht a chur i bhfeidhm agus tuairisciú ar an reachtaíocht sin.

Bainistíocht Uisce

> Plé le struchtúir náisiúnta agus réigiúnacha rialachais agus oibriúcháin chun an Chreat-treoir Uisce a chur i bhfeidhm;
> Monatóireacht, measúnú agus tuairisciú a dhéanamh ar chaighdeán aibhneacha, lochanna, uiscí idirchreasa agus cósta, uiscí snámha agus screamhuisce chomh maith le tomhas ar leibhéil uisce agus sreabhadh abhann.

Eolaíocht Aeráide & Athrú Aeráide

> Fardail agus réamh-mheastacháin a fhoilsiú um astaíochtaí gás ceaptha teasa na hÉireann;
> Rúnaíocht a chur ar fáil don Chomhairle Chomhairleach ar Athrú Aeráide agus tacaíocht a thabhairt don Idirphlé Náisiúnta ar Ghníomhú ar son na hAeráide;
> Tacú le gníomhaíochtaí forbartha Náisiúnta, AE agus NA um Eolaíocht agus Beartas Aeráide.

Monatóireacht & Measúnú ar an gComhshaol

> Córais náisiúnta um monatóireacht an chomhshaoil a cheapadh agus a chur i bhfeidhm: teicneolaíocht, bainistíocht sonraí, anailís agus réamhaisnéisiú;
> Tuairiscí ar Staid Thimpeallacht na hÉireann agus ar Tháscairí a chur ar fáil;
> Monatóireacht a dhéanamh ar chaighdeán an aeir agus Treoir an AE i leith Aeir Ghlain don Eoraip a chur i bhfeidhm chomh maith leis an gCoinbhinsiún ar Aerthruailliú Fadraoin Trasteorann, agus an Treoir i leith na Teorann Náisiúnta Astaíochtaí;
> Maoirseacht a dhéanamh ar chur i bhfeidhm na Treorach i leith Torainn Timpeallachta;
> Measúnú a dhéanamh ar thionchar pleananna agus clár beartaithe ar chomhshaol na hÉireann.

Taighde agus Forbairt Comhshaoil

> Comhordú a dhéanamh ar ghníomhaíochtaí taighde comhshaoil agus iad a mhaoiniú chun brú a aithint, bonn eolais a chur faoin mbeartas agus réitigh a chur ar fáil;
> Comhoibriú le gníomhaíocht náisiúnta agus AE um thaighde comhshaoil.

Cosaint Raideolaíoch

> Monatóireacht a dhéanamh ar leibhéil radaíochta agus nochtadh an phobail do radaíocht ianúcháin agus do réimsí leictreamaighnéadacha a mheas;
> Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha;
> Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta;
> Sainseirbhísí um chosaint ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Ardú Feasachta agus Faisnéis Inrochtana

> Tuairisciú, comhairle agus treoir neamhspleách, fianaise-bhunaithe a chur ar fáil don Rialtas, don tionscal agus don phobal ar ábhair maidir le cosaint comhshaoil agus raideolaíoch;
> An nasc idir sláinte agus folláine, an geilleagar agus timpeallacht ghlan a chur chun cinn;
> Feasacht comhshaoil a chur chun cinn lena n-áirítear tacú le hiompraíocht um éifeachtúlacht acmhainní agus aistriú aeráide;
> Tástáil radóin a chur chun cinn i dtithe agus in ionaid oibre agus feabhsúchán a mholadh áit is gá.

Comhpháirtíocht agus Líonrú

> Oibriú le gníomhaireachtaí idirnáisiúnta agus náisiúnta, údaráis réigiúnacha agus áitiúla, eagraíochtaí neamhrialtais, comhlachtaí ionadaíocha agus ranna rialtais chun cosaint chomhshaoil agus raideolaíoch a chur ar fáil, chomh maith le taighde, comhordú agus cinnteoireacht bunaithe ar an eolaíocht.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil

Tá an GCC á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóir. Déantar an obair ar fud cúig cinn d'Oifigí:

1. An Oifig um Inbhunaitheacht i leith Cúrsaí Comhshaoil
2. An Oifig Forfheidhmithe i leith Cúrsaí Comhshaoil
3. An Oifig um Fhianaise agus Measúnú
4. An Oifig um Chosaint ar Radaíocht agus Monatóireacht Comhshaoil
5. An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tugann coistí comhairleacha cabhair don Ghníomhaireacht agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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