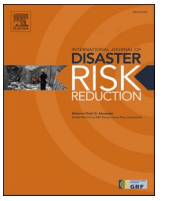
International Journal of Disaster Risk Reduction 91 (2023) 103687

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr



Weathering the storm: Developing a user-centric weather forecast and warning system for Ireland

Gavin D. Brown *, Ann Largey, Caroline McMullan, Niamh Reilly, Muskan Sahdev

Dublin City University, DCU Business School, Glasnevin Campus, Dublin, Ireland

ARTICLE INFO

Keywords:
Weather warnings
Weather forecasts
Protective action
Public confidence
Severe weather

ABSTRACT

This paper appraises current usage and future weather service needs in Ireland. The data for this study were collected using a household preparedness questionnaire and focus groups with urban communities, rural dwellers, and marine users, farmers, students, and an island community. The questionnaire was used to collect data on weather warnings and preparedness following a category red severe weather warning. Data on participants' need for weather forecasts and warnings, current and future weather service requirements, and the effectiveness of the National Meteorological and Hydrological Service (NMHS) were collected from the focus groups.

Our analysis identifies the importance of accurate weather forecasts to the public and groups such as farmers as they plan their professional and private lives. Participants were aware of the weather warning system's color-coded structure, with the highest-level warnings considered most effective in capturing attention. Most participants spoke negatively about category yellow warnings, as they perceived them to be issued too frequently. Experience of warnings being issued and threats failing to materialize caused a minority of participants to ignore warnings and not take preparedness action. The professionalism of the NMHS was praised by focus group participants, and there was a high level of overall satisfaction with the quality of the national weather warning system (75.1% of survey participants were mostly or extremely satisfied).

Opportunities to improve weather services included enhanced communication with service users, improved web and app interfaces, a move to probabilistic forecasting, and weather warnings that encompass calls to action.

1. Introduction

Island nations, such as Ireland, which experience rapidly changing weather systems, are particularly reliant on accurate weather forecasting and an effective weather warning system. Hydrometeorological services must, therefore, provide necessary weather and preparedness information through these forecasts and warnings to enable communities and partners prepare for and respond to extreme weather events [1]. These hydrometeorological services also play a vital role in motivating citizens' adaptation and promoting resilience to severe weather [1]. To support users in their decision making, the World Meteorological Organization (WMO) [2] emphasized the need for a user-centric model of weather forecasts and warnings: an approach which aligns with The First Mile concept

Abbreviations: WMO, World Meteorological Organization; NMHS, National Meteorological and Hydrological Services; NRA, National Risk Assessment; IFRC, International Federation of Red Cross and Red Crescent Societies.

* Corresponding author.
E-mail addresses: gavin.brown@dcu.ie (G.D. Brown), ann.largey@dcu.ie (A. Largey), caroline.mcmullan@dcu.ie (C. McMullan), niamhmichelle.reilly5@mail.dcu.ie (N. Reilly), muskan.sahdev2@mail.dcu.ie (M. Sahdev).

https://doi.org/10.1016/j.ijdrr.2023.103687
Received 26 May 2022; Received in revised form 1 March 2023; Accepted 10 April 2023
Available online 17 April 2023

that places users at the beginning, rather than the end, of the weather forecasting and warning design process [3–5].

The purpose of our study was to determine the current and future weather service needs of the general public and specialist interest groups, with particular emphasis on the effective communication of weather forecasts and weather warnings. The findings will underpin the delivery of the Strategic Plan (2017–2027) of Met Éireann, the Irish National Meteorological and Hydrological Services (NMHS), to improve customer services and inform the development of impact-based forecast services.

1.1. Background

Weather forecasting has a degree of uncertainty in relation to location, timing, intensity, and level of impact. To help quantify this uncertainty and determine the most likely scenario, the Irish NMHS utilizes an Ensemble Prediction System [6]. This scenario is then provided to the public as a single predicted weather forecast, with no reference to the probability of occurrence.

Research examining US weather forecasts has shown that when people are provided with a forecast without uncertainty information they attempt to estimate uncertainty; perhaps inaccurately [7,8]. Morss *et al.* found that as the lead time for a forecast increased, respondents' confidence in the forecast reduced and concluded this "suggests that many respondents have a general sense of the relative accuracy or uncertainty in different types of weather forecasts" ([7]; p.987). Uncertainty in weather forecasting, and confidence in the weather forecasts, will also be explored in our study.

Providing uncertainty information could improve understanding of the forecast and assist service users in making more effective decisions [9,10,11]. Kox *et al.* established that in Germany emergency service personnel had less confidence in deterministic forecasts, which give a single prediction, when compared to forecasts which report probabilistic information [10]. Just as Irish warnings include general statements such as "Storm Barra is expected to bring severe and damaging wind gusts" ([12]) Kox *et al.* noted that Germany's weather warnings also use qualitative statements about uncertainty (e.g., very likely) [10]. They found that German users would prefer warnings to contain a range of values and probabilities in addition to the deterministic statements [10]. The preferences of Irish service users will be determined in this paper.

In a US study conducted by Carr *et al.* , information about a hypothetical hurricane scenario was presented to focus group participants to examine how they used and interpreted an ensemble flood forecast [11]. They found the different clusters of users (water resource managers, emergency managers and residential users) reacted differently to the forecast information, and that changes in how the graphics were presented, e.g., "a detailed legend with range of probabilities", appeared to improve "the ability of residents to understand uncertainty" ([11]; pp.1369-1370). Their findings highlighted the importance of reducing uncertainty in forecasting and

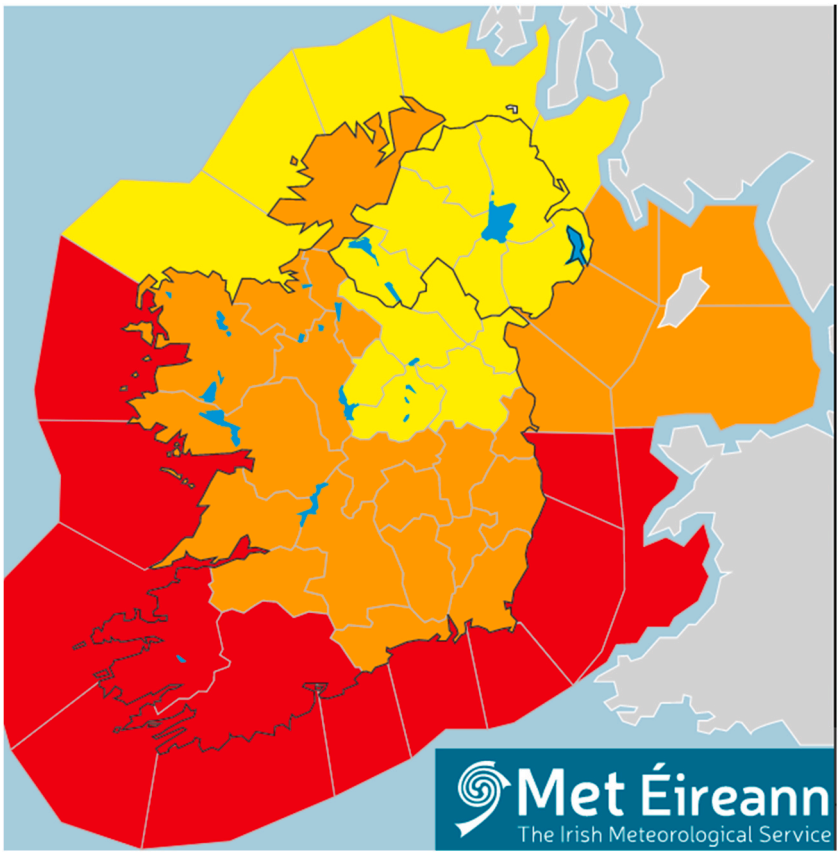


Fig. 1. Sample warning showing weather warnings issued across Ireland.

the need to gain a greater understanding of how forecasts are perceived and acted upon. A key focus of our paper will be to add to this understanding of how forecasts and weather warnings are perceived and acted upon by the general public and specialist service users in Ireland.

Once a warning is issued, several outcomes can occur: a false alarm; an over-warning (less severe than forecast); an accurate warning; or an under-warning (more severe than forecast) [13]. False alarms or over-warned events are more likely to occur than missed warnings [14] and warnings are issued to more people than are likely to experience the impacts [15]. The implication of false alarms is that users may not react to future warnings: the cry wolf effect [15]. There are, however, inconsistent results on the existence of this cry wolf effect [16]. Walters *et al.* in the US found that false alarms did not negatively impact households' responses to tornado warnings [16]. Likewise, Barnes *et al.,* who also examined tornado warnings in the US, suggested the public could have a high acceptance of false alarms [13], while research by Ripberger *et al.* also in the US, concluded that false alarms and missed events contributed to perceptions of inaccurate tornado warnings, which in turn led to lower levels of trust in the NMHS and reduced compliance and action [17]. LeClerc and Joslyn who sampled US university students found, however, that the inclusion of estimates of uncertainty within weather warnings associated with low temperature events enhanced credibility, even in the case of a false alarm, as there was transparency from the outset [18]. The cry wolf effect, trust, and the overall impact of false alarms are themes explored in our research.

While the literature review informed the design and focus of our study, the absence of Irish research meant it was not possible to determine if their findings apply in Ireland. The findings of our research will allow us to determine if the US and German results are confirmed in an Irish context.

The NMHS in Ireland provides weather forecasts and warnings via radio and television broadcasts, their website and mobile app, and social media channels. At present, users must opt-in to receive county and national-level weather information (including weather warnings). The Irish NMHS uses a threshold weather warning system with three escalating categories [19]:

- Status Yellow: Be Aware
- Status Orange: Be Prepared
- Status Red: Take Action

These warnings, which are mapped and described in a mix of prose and thresholds (see Fig. 1 and Table 1), are issued by county or sea area, even though the severe weather may not impact the entire area equally; reflecting Meyer and Kunreuther's observation that a wider area will be covered by the warning than will be impacted [15].

Public warning and alert systems focus public attention on an approaching risk and can afford more time to prepare. However, studies conducted in North America, although not directly comparable to Ireland, have shown that the warnings/terminology related

Table 1
Weather warning thresholds.

Warnings Levels	Warning Criteria
Status Yellow	Weather that does not pose a threat to the general population but is potentially dangerous on a localized scale. For example: • Widespread mean speeds between 50 and 65 km/h • Widespread gusts between 90 and 110 km/h • Snow/Ice: 3 cm or more in 24 h • Low Temperature/Ice: Air minima of minus 3C or minus 4C expected over a wide area (localized lower values will occur). Dangerous surfaces due to ice and/or lying snow. Situation improving.
Status Orange	Infrequent and dangerous weather conditions which may pose a threat to life and property. For example: • Widespread mean speeds between 65 and 80 km/h • Widespread gusts between 110 and 130 km/h • Snow/Ice: o 3 cm or greater in 6 h o 5 cm or greater in 12 h o 10 cm or greater in 24 h • Low Temperature/Ice: Air minima of minus 5C to minus 10C (or lower) expected over a wide area. Dangerous surfaces due to ice and/or lying snow/freezing rain. Situation stable.
Status Red	Rare and very dangerous weather conditions from intense meteorological phenomena. For example: • Widespread mean speeds in excess of 80 km/h • Widespread gusts in excess of 130 km/h • Snow/Ice: o 10 cm or greater in 6 h o 15 cm or greater in 12 h o 30 cm or greater in 24 h • Low Temperature/Ice: Air minima minus 10C (or below) for three consecutive nights or more. Maxima of minus 2C. Dangerous surfaces due to ice and/or lying snow/freezing rain. Situation likely to worsen.

to extreme events such as tornadoes or flash floods are often misunderstood [17,20–22]. Taylor *et al.* in a study of the UK public's interpretation of wind warnings, showed that clarity and ease of understanding built confidence in the warning system and the NHMS [23]. The Irish NMHS uses color-coding to differentiate between different levels of risk, however Taylor *et al.*, cautioned that color-coded warnings are not always intuitive, and misunderstandings can occur [23]. Our research will also explore how the public interpret of weather warnings in Ireland, allowing for a comparison with international findings.

To achieve Goal 1 of Met Éireann's strategic plan, "Enhance support for impact-based decision making for weather events" ([24]; p.16), Ireland's NMHS is moving from threshold-based warnings, as described above, to impact-based warnings that consider the vulnerability, location, and weather risk of individuals, communities, and services in line with WMO guidelines [25]. During the transition to this impact-based forecasting approach, thresholds are still used to determine warnings, but the likely impacts of any weather event will increasingly inform the severity of each warning issued (Hally 2022). According to the International Federation of Red Cross and Red Crescent Societies (IFRC) and UK Met Office ([26]; p.13), "Impact-based forecasting enables anticipatory actions and revolutionizes responses to weather and climate crises: turning forecasts and warnings from descriptions of what the weather will be … into assessments of what the weather will do enables organizations and individuals across the world to anticipate and take action to mitigate the impacts brought by weather and climate events". Understanding location-specific weather-related vulnerabilities, such as each local community's unique environmental and societal characteristics, is an important aspect of achieving a user-centric approach to warnings [27]. These observations are echoed by Potter *et al.* who examined the benefits and challenges of impact-based forecasting and warning systems for severe weather by interviewing meteorologists in the UK, France, and Switzerland, and holding workshops in New Zealand with government hydrologists and those from the emergency management sector [28]. found that impact-based forecasting and warning systems are often designed for responding stakeholders and not individuals in society and emphasized the need for a deep understanding of local vulnerabilities and coping capacities to improve warnings effectiveness, and the need to collect and store impact data as events occur to inform future warnings.

To improve the communication of a warning, Bostrom *et al.* suggested that vulnerabilities and impacts need to be emphasized in warnings [29]. Failure to do so may result in appropriate protective actions not being taken [30,31] because people may not know how to respond. Including a call to action or guidance in a warning increases the likelihood that the public will act [32], especially where warnings also emphasize impacts [33,34]. Warnings must be viewed as personally relevant and action-orientated [35].

For warning systems to be most effective at encouraging action, they must integrate the elements of "detection of extreme events, management of hazard information, and public response and also maintain relationships between them through preparedness" ([35]; pp.174–175). Ongoing engagement with the public, using preparedness messaging for example, provides a platform for household preparation and pre-warning awareness [27]. This ongoing engagement aligns with the view that the warning system does not simply begin when the risk first materializes [35,36]. Education, public engagement, and outreach activities should continuously encourage household preparedness behaviors and actions [36].

The purpose of a warning system is to encourage individuals to take the best possible preparedness actions given their circumstances. Protection Motivation Theory (PMT) suggests once individuals are aware of a risk, their decision to take protective action is primarily influenced by two appraisals: threat and coping [37]. In the threat appraisal, an individual performs a risk assessment to ascertain the level of threat a risk poses based on its likelihood of occurrence and associated impacts [37]. However, the effectiveness of the threat appraisal in prompting preparedness action has had mixed results [38–46]. During the coping appraisal, the individual weighs the effectiveness of proposed protective measures, their capacity to take protective action, and the expected costs (time and money) against the magnitude of the threat [37]. For warnings to be most effective at promoting action, they should focus on enhancing households' coping appraisal [47]. This can be achieved by providing information about what preparedness actions to take, along with how these actions can make a difference, and ultimately working to build households' confidence in their ability to take the actions [40,46,48].

Following on from PMT, Mileti and Sorensen ([49]; p.5–1) describe a "social-psychological process that people go through in a warning situation from the time a first warning is heard to the time people respond". The process known as warning response comprises several stages, but not all are required for protective actions to be taken [49]. These stages are summarized: (1) people must realize the threat–"hearing the warning"; (2) they must understand the threat and the corresponding warning–i.e., they must relate to the message, perceive the risk to be high (which relates to PMTs threat appraisal) and have knowledge of what action can be taken; (3) they must have confidence in the warning's accuracy, belief in the warning's credibility; (4) they must assess how the threat will impact them, enabling a response to the corresponding warning; (5) decide whether to take action; and (6) constantly validate the information received and source new information as required [35,49,50]. Our research will also explore how weather warnings influence preparedness action and how the effectiveness of warnings can be enhanced.

Risks arising from severe weather dominate the socio-natural risk classification of the Irish National Risk Assessment (NRA). The reasonable worst-case scenarios documented in the NRA [51] are:

A) Storm: "equal to the magnitude of Storm Ophelia which triggered a nation-wide red level warning and made landfall over Ireland on 16 October 2017. Winds reached an observed wind speed of 156 km/h and a mean of 60 km/h" [51]; p.24).
B) Snow and Ice: A snowstorm of the magnitude of Storm Emma (28 February and 4 March 2018): "According to the analysis report of Storm Emma and the cold spell which struck Ireland by Met Éireann, this was one of the most significant snowfall events of recent years saw temperatures plummet with widespread snowfall across the country" [51]; p.24).
C) Flood: "of the magnitude of the 2015/16 Shannon river flood, when one third of river-level gauges recorded their highest readings ever. The assessed impact reflected sustained duration flooding, impacting severely on communities with significant disruption to daily life and access to services" [51]; p.25).

The NRA also addressed the cross-border dimension of each of these risks and acknowledged the importance of cooperation between the NMHS in Ireland and the UK and coordination in terms of managing the consequences of severe weather on the island of Ireland [51].

2. Research methodology

To inform the delivery of user-centric national weather services, this study, the first of its kind in Ireland, (1) captured the public's use of weather forecasts; (2) investigated public confidence in weather forecasting; (3) examined public perception and reaction to weather warnings; and (4) identified future weather service needs.

Data were gathered using a questionnaire, administered in May–June 2018, and a series of focus groups with members of the Irish public in February–March 2021, approved by the University Ethics Committee. A volunteer sampling method was used to recruit participants via social media posts and email contacts.

2.1. Data collection procedures

An online questionnaire, issued between May and June 2018, approximately eight weeks after a severe weather warning associated with Storm Emma, was used to collect data on household preparedness, including respondents' satisfaction with the NMHS weather warning system and their response to weather warnings. Storm Emma was a severe weather event which occurred towards the end of the winter of 2018, causing record low temperatures, blizzard conditions and widespread disruption. A nationwide red weather warning and curfew was issued in response [52] [53]. The weather conditions Ireland experienced during Storm Emma had not been experienced for almost 36 years [52,53].

The questionnaire was shared on social media (e.g. Twitter; Facebook; LinkedIn) and was reshared by a wide range of individuals and organizations such as the NMHS, Local Government, and the national Office of Emergency Planning.

Anonymized responses were received from 4451 households whose socio-demographic characteristics were in line with the 2016 Irish census data; 64.9% earned less than €70,000 (nationally 62.6% had a gross income of less than €60,000), and 70.1% owned their home compared with 67.6% homeownership across Ireland [54,55]. Furthermore, the Central Statistics Office reported that 31.4% of people in Ireland lived in a rural area, closely matching the sample data of 30% [56].

Eight focus groups, conducted via Zoom, were carried out from February to March 2021 to gather data on participants' need for weather forecasts and warnings, current and future weather service requirements, and the effectiveness of the NMHS. Four focus groups drew participants based on geographic location (two urban, two rural), and four from special interest groups (marine recreational users, the agricultural sector, 3rd level students, and those living in a small island community). A total of 53 members of the public took part in the eight focus groups, comprising 25 females and 28 males. The number of participants per group ranged from 4 to 8 and lasted approximately 90 min. Figure A1 within the appendix provides a map showing locations of the focus groups. To recruit participants, advertisements were shared on social media and targeted messages were sent to groups such as sailing clubs, community groups and farming organizations. Interested participants were grouped by geographic location or special interest. From these clusters people were randomly selected and invited to participate in a focus group. Details of the focus groups and coding used in presenting quotes are documented in Table 2. Focus groups were conducted using a semi-structured approach using open questions so as not to stifle dialogue [57], and each lasted approximately 90-min. A copy of the focus group questions is provided in the Appendix.

Questionnaire respondents were also given an alphanumeric pseudonym to preserve their anonymity. QR represents a Questionnaire Response – followed by a unique identifier (e.g., QR334).

2.2. Data analysis

Analysis of the questionnaire data on satisfaction with the NMHS weather warning system and preparedness action was conducted using descriptive statistics, t-tests, and chi-square tests in STATA (StataCorp-16.1/SE). The focus group transcript data were uploaded to NVivo R1.4.1 and analyzed using [58,59] 6-phase thematic analysis technique.

Table 2
Focus groups.

Focus Group	Code	Date (2021)	Participants	Unique Identifiers	Gender
Geographic Urban Regions					
Dublin	U1	February 26th	Eight	U1P1 to U1P8	5 Females; 3 Males
Cork	U2	March 15th	Seven	U2P1 to U2P7	3 Females; 4 Males
Geographic Rural Regions					
Rural 1: Donegal/Mayo/Leitrim/Sligo	R1	March 10th	Seven	R1P1 to R1P7	3 Females; 4 Males
Rural 2: Westmeath/Cavan/Monaghan/Louth	R2	March 12th	Eight	R2P1 to R2P8	3 Females; 5 Males
Special Interest Groups					
3rd Level Students	S1	February 19th	Eight	S1P1 to S1P8	4 Females; 4 Males
Marine (Recreational) Users	S2	March 3rd	Six	S2P1 to S2P6	3 Females; 3 Males
Agriculture	S3	March 8th	Six	S3P1 to S3P6	2 Females; 4 Males
Island (Inishbofin)	S4	March 18th	Four	S4P1 to S4P4	2 Females; 2 Males

Note: Focus group participants were given an alphanumeric pseudonym to preserve their anonymity (e.g., U1P1 = Urban 1-Participant 1).

2.3. Research limitations

Although an open invitation to participate in this study was issued to any user of Twitter, Facebook, and LinkedIn, as well as the targeted groups outlined above, participants were with a particular interest in the topic of weather and forecasting were more likely to respond in the first instance, which introduces the potential for bias. That said, participants exhibited a variety of opinions and responses appeared to be diverse and not prone to social desirability bias. For example, focus group participants were not quick to agree with each other, and discussed topics from various viewpoints.

For the purposes of this research, the focus groups were selected based on specific criteria: geographic location and special interest. While participants were taken at random based on these specific criteria, the findings associated with the focus groups were not intended to be generalizable to the general population and instead allowed for more in-depth probing into the attitudes, experiences, and behaviors of the participants. To counterbalance for the lack of generalizability, the large number of questionnaire respondents (4451) provided broader and more representative data.

3. Findings: results and discussion

A summary of the thematic analysis is provided within the Appendix in Tables A1 to A7. Themes and sub-themes were coded into clusters. Relating to forecasting (Table A1 to A4) nine major themes emerged: how participants accessed the forecast, why they checked the forecast, the importance of accuracy, the importance of the forecast, their confidence in the forecast, frequency of use, which weather apps were used and why, marine services and the NMHS roles and services. Table A5 sets out five major themes related to weather warnings, namely: notification sources of the alert, declared familiarity with the warnings color scheme, familiarity with the weather warnings in practice, perceived effectiveness of the system, and suggestions for improvement. Table A6 sets out the questionnaire respondents' satisfaction with the Weather Warnings under negative and positive sentiment. Table A7 outlines three major themes regarding how participants responded to the weather warnings: changes in behavior, protective action taken, and no action or behavioral change.

3.1. Forecast sources and preferences

As a result of the growth of the private meteorology sector, people can source their forecasts from various providers and are not limited to the NMHS [60,61]. The focus groups confirmed this with the most frequent services mentioned being: Met Éireann (Irish NMHS), Google, iPhone, Yr, Windguru, BBC, XC Weather, AccuWeather and Magicseaweed. While focus group participants had their preferred forecast sources, confidence in the information provided by the NMHS was high, especially among the Agricultural and Student Groups.

Those who preferred the NMHS generally selected the NMHS for its accuracy, ease of accessibility (access on phone/computer and via broadcasts on television and radio), its rainfall radar feature, professionalism, and reliability:

> I think that actually Met Éireann presents a very professional, if you watch them on screen, …they're very professional. (R2P8)

> I think Met Éireann does a particularly good job. I mean, probably everybody in Ireland will watch the RTÉ news service every night and I have, the Met Éireann app on my phone, which I check … regularly. (U2P3)

When participants spoke of their satisfaction with the forecast provided by other providers, not the NMHS, six focus groups highlighted accuracy, five groups highlighted the importance of ease of interpretation and accessibility (e.g., app design: interface and visuals) Participants seldom mentioned the characteristics of the service provider such as "professionalism".

In cases where the coded themes associated with choosing the NMHS, or not, were similar, for example accuracy or accessibility, preference appeared to be driven by judgements on the quality of one service over another, the availability of specific features, or sometimes simply convenience (e.g., the default weather app supplied on the phone). These findings emphasize the importance of engaging with people to understand their needs and wants. For example, the user interface of the NMHS app was criticized by several people the Agriculture, Marine Users, Students, Dublin, and Cork groups; with Marine Users and Students most vocal. In contrast, they praised the interface of some competitor apps for being user-friendly with their use of graphics and probability percentages making them easier to read:

> One of the only differences I could note from looking at what the Met Éireann app looks like, it's quite wordy like they will have the weather forecast in sentences, as well as actually a map of Ireland, whereas … the iPhone one has percentages and it'll have a rain cloud or like my one, I think it just goes by the hour and if there's just a cloud if it's cloudy, if there's a sun it's just sunny, that sort of thing. You kind of just get it from pictures or like little icons, rather than actually reading sentences. Maybe as a generation we're just lazy but like it's just kind of easier just to see. (S1P4)

The accuracy and usefulness of the NMHS Rainfall Radar was specifically praised in three focus groups: Agriculture, Marine Users and Dublin groups. It provides users with real-time rainfall data and, as a result, the ability to determine when rainfall may reach their area. Real-time data reduces the need for service users to estimate the likelihood of the risk occurring in their locality. As one person noted:

> … the radar is always going to give you a better picture of the risk, not necessarily whether it would rain or not. (S3P3)

It was described as an essential aid to farmers' decision-making regarding spraying pesticides, mowing, or bagging grass for silage. The Marine Users and Student Groups also spoke favorably about this feature:

> So, I think the rainfall radar is a great asset, and it is live, and it's probably the most accurate forecast you can get in that respect. If there was only something of equivalent nature for the wind it'd be excellent. (S2P5)

Irrespective of which forecast provider they used, participants in all eight focus groups underlined the need for accurate weather forecasts to plan for work and leisure activities. Reasons for checking the weather forecast were scheduling exercise and social activities or for choosing clothing on a particular day. For others, the prominent reasons for checking the weather forecast were safety concerns or planning work. For these people, accuracy was essential to inform decision making where livelihoods depended on weather conditions and those living in remote island communities. These individuals needed to be aware of any upcoming unusual weather to change their planning, sometimes before a weather warning was issued.

Residents of Inishbofin Island rely on accurate forecasts for their safety and when planning their daily activities, particularly for trips to the mainland. They also recognized the vital role accurate forecasts and the regular broadcasts by the NMHS have played in reducing weather-related disasters:

> It's enormously important. … because it's not only just a rural community, it's also an island community, and weather has an enormous effect on what you do. And the accuracy of forecasts is hugely important. … Since the infancy of weather forecasting, it's hugely important to anyone that's involved in anything such as fishing or ferrying or operating any sort of a vessel or any sort of a marine life at all. Forecasting is enormously important and always has been. Traditionally like, there's been a lot of disasters in the past that have happened here, historically, and most were down to the lack of a forecast; storms blow up on people, unpredictable storms. No matter how skilled you are, stuff will happen … When the forecasts came along, and accurate forecasts came along, and Met Éireann and regular broadcasts, a lot of those sudden storm type disasters stopped. (S4P3)

Similar points were reflected by marine leisure users and farmers, where safety and planning relied on accurate weather forecasts:

> Well, an inaccurate weather forecast can be deadly … (R1P6)

> If you're spraying on agrochemicals, you just can't afford to have it washed off. (S3P3)

3.2. Confidence in weather forecasting

Participants across all eight focus groups expressed a lack of confidence in weather forecasting. The lack of accuracy was discussed in all but the Inishbofin group, and participants in all but the 2nd Rural focus group lacked confidence in the information they received:

> Sometimes the forecast can be "fairly" accurate, but I generally find that there is a lot of variance in what is being said. For example, showers with sunny spells or sunshine with scattered showers. You can't really go wrong with these types of statements. (R2P4)

Taylor *et al.* highlighted the difficulty in maintaining confidence in forecasting, given that a forecast often changes depending on the lead time [62]. In the focus groups, participants understood how lead times affect accuracy in forecasting. For example, more participants were confident in the forecast three days out or sooner, but no participants described long-range forecasts (greater than one week) as accurate. They also appreciated that certain weather conditions are easier to predict with certainty over longer time frames:

> Once you go beyond the two or three days, it is more shaky, and everything else, because you can often see quite a bad forecast has been given. And, you know, after a couple of days, it just may change around completely, and an opportunity may present itself in relation to getting the work done. (S3P2)

To improve confidence in the NMHS forecast, several participants within six focus groups (excluding Students and Marine User groups) suggested it needed to become more localized:

> A very local forecast would be great, to within a few miles radius. (S3P5)

> … [greater] localization and by localization, I mean, within a certain kilometer of where you are, you know. (R1P3)

A desire for greater reliability beyond a three-day timeframe was also expressed across all focus groups, and some participants, most especially in the 2nd Rural focus group, hoped technological developments in the forecasting may lead to greater accuracy in longer-range forecasting.

As the NMHS provides a single forecast detailing the most likely predicted outcome, with no probability data, all eight focus groupscalled for a move to probabilistic forecasting focused on occurrence and magnitude. While some preferred detail, many expressed a preference for shorter, more factual forecasts:

> I would like to see the probability being introduced. It works in many other countries. And it would help, you know, if you have the rain on the forecast. Well, is it a 10 percent chance of rain or a 90 percent chance of rain? It influences the risk you'll take. And that's useful in so many different corners. And I think when they get there, I would love to see them put in probability on their monthly forecast, because in a few years' time, they may very well have a reasonably good handle on what's going to happen in week three and week four. (S3P3)

> People now want precise information, …there's a 70 percent chance it's going to rain at 11 o'clock in the morning tomorrow. (R2P3)

The focus groups confirm previous US and European based studies that providing uncertainty information within a forecast can inform users' decision making [9,63]. However, this does not suggest ambiguity may be removed entirely, as probabilistic forecasting still requires the users' interpretation [64]. Given that the Ensemble Prediction Systems used by the NMHS already generate uncertainty estimates for each scenario, the NMHS could and should switch to the presentation of probabilistic forecasts.

Discussions on a lack of confidence in weather forecasting also highlighted that some participants from five of the focus groups (Dublin, Marine Users, Students, Agriculture, and the 2nd Rural group) crosschecked multiple weather forecasts to determine what they believe to be the most likely scenario:

> I use a combination of every available weather forecast and make me mind up from them all, basically! Got to do with looking on my phone, got to do with BBC weather forecast, got to do with RTÉ, and I make an assumption based on all. If two out of the three are predicting something and the other isn't … it's more liable that that's going to happen. And that's how I base my assumptions upon. (R2P6)

Prior research from the US has suggested that conflicting and contradictory information across forecasts can lower users' confidence [65,66], which can be a barrier to effective decision-making [65]. Yet, in these focus groups, some participants appeared to expect, or at least accept, inconsistencies between the forecasts, hence their use of multiple sources. These verification actions are documented by Mileti [35] and provide evidence that as part of the weather warning process, some users will continue to crosscheck information by conferring with others and consulting several sources, a behavior comparable to "milling" ([67]; p.1 [68]; p.537). In the absence of greater localized forecasting technology becoming immediately available to all forecasting services, and given the range of forecast providers, it is probable conflicting and contradictory information will continue. As part of the user-centered approach, the NMHS could engage with local communities to improve their understanding of how local environmental factors affect their weather, thus working to improve confidence in the NMHS forecasts: e.g., how local mountains affect precipitation levels in certain areas. That information could be attached to the NMHS weather app using location data.

3.3. Weather warnings: information sources, perception and reaction

Survey respondents were asked to identify the information sources they used during major emergencies in Ireland. These sources were news media (92.76%), Government Authorities (52.66%), social media or websites (41.31%) and word of mouth from family and friends (40.05%). All focus groups reported similar sources of information when discussing weather warnings, with the most common source mentioned again being various news media bulletins: news broadcasts on TV and radio and warnings received via pop-up notifications from a news app. Other frequently discussed methods included social media (six focus groups), the Irish NMHS (five focus groups) and word of mouth, typically involving a friend or family member, (four focus groups). A few participants from three of the focus groups mentioned receiving notifications of weather warnings through work or text/email alerts.

Survey respondents rated their satisfaction with the NMHS weather warning system from extremely dissatisfied (coded as 1) to extremely satisfied (coded as 7). Most respondents (88.2%, 3416n) were at least somewhat satisfied with the system, see Fig. 2.

The overall satisfaction with the Met Éireann weather warning system was 5.91. Average satisfaction decreased with urbanicity. Respondents from rural settings gave the weather warning system a higher average satisfaction rating (6.01) than respondents living in a city (5.69). This difference is highly significant based on a *t*-test ($t = 4.50$, $p = 0.001$). See Supplementary Material 5 for results related to a difference by gender.

Survey respondents who were not "Extremely Satisfied" with the NMHS weather warning system provided additional feedback. 38.5% (953n) suggested warnings were issued too frequently, while 14.7% (363n) indicated they were challenging to understand. These respondents were invited to expand upon their quantitative responses and 818 respondents provided 1008 statements concerning their satisfaction with the weather warnings. It was evident from the outset of the analysis that respondents were divided with 44.05% (444n) of the comments being positive in nature. The prevalent themes that emerged are discussed below, along with an overview of these themes provided in Table A6 of the appendix. Further, Table A8 reports the gender balance in both positive and negative themes related to respondents' sentiment concerning weather warnings.

When discussing the positive aspects of weather warnings, those most frequently mentioned in the questionnaires and subsequent focus group discussions were that overall the system worked well (emerged in all but the Marine Users focus group), increased awareness of the forecasted severe weather (emerged in the Agriculture, Cork and both Rural focus groups), and the warnings were clear (discussed in Dublin, Agriculture, and 1st rural focus groups):

> Very easy to understand and only issued when necessary (QR677)

> Helpful to people to give advance warning of potentially dangerous weather which allows them to prepare for same (QR3315)

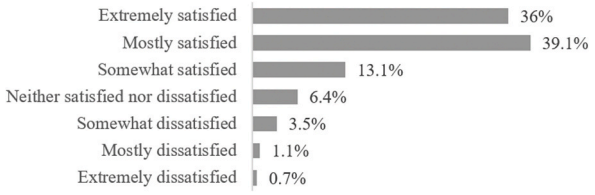


Fig. 2. Satisfaction with the NMHS weather warning system.

A small number of participants across the Agriculture, Dublin, Cork, and Rural focus groups also emphasized that the weather warnings provided critical information:

> I think largely they are a great tool to give people advanced notice (R2P4)

The most prevalent negative aspects mentioned in the questionnaires and subsequent focus group discussions were that warnings, especially yellow, were issued too frequently (discussed in all eight groups), lacked accuracy (emerged in all eight groups), and were not taken seriously or understood fully (mentioned within six focus groups – excluding Cork and the Agriculture focus groups). When discussing a lack of accuracy, some participants suggested the warnings were poorly timed, but most referenced weather events that did not materialize as forecast. Linked to a lack of confidence in the accuracy of a warning, participants suggested the warnings were too generalized:

> … I do think that it can be also very generalized and, you know, because even within a county, I think you can have different weathers on the same day. And if you're going to apply it, don't apply it in a generic way. (R1P3)

Yeah, I would agree with you that they are fairly generalized. Like in Leitrim, there could be a hell of a difference between the weather in Kinlough in the north end and Carrick-on-Shannon in the south. I mean, it's more than an hour's drive, so an awful lot can be happening there. (R1P6).

> They should be more specific to local areas … (QR3771)

Drawing on the questionnaires, some respondents raised problems with understanding the color-coded system, suggesting the threat posted or actions needed were not clear:

> I think that people don't really understand what they mean and so there is confusion behind why a certain weather warning is in place. There is an expectation that if we have a red weather warning that the weather will be very severe without an understanding that the risks may lie in other factors such as fallen trees fallen electricity wires etc. (QR2609)

> Yellow and orange warnings - severity difficult to understand (QR1244)

> What does Yellow and Orange even mean? Should we care about Yellow? (QR4662)

While focus groups participants were aware of the color coding associated with weather warnings, their knowledge and understanding beyond that was limited. Associating warnings' colors to the alert level was effective in conveying a level of threat, as participants understood the sequence of three warning colors and that a red warning was most severe. But it did not provide the necessary context to understand the specific features of the threat, and after confirming the sequence of the three colors, many participants, including some from the Dublin, Cork, Students, Inishbofin and Rural focus groups, would hurriedly follow up to express feelings of an incomplete understanding:

> I think there's nearly a stereotype around that because the system's been here for what seems like a while, that people actually have an understanding of it, that we're kind of like creatures of habit, that we just know what to do for each sort of weather warning. Whereas, we don't. … the simplest ways to do it, like from RTÉ without causing a big, massive panic, like just sort of an explanation of what it is, just a brief education on what the actual system is, rather than just assuming that we know it. (S1P6)

> I wouldn't have known the implications of an orange versus a red. You might know a yellow to red is more serious. But the one in between, I have no idea what an orange actually means and how severe it actually is. (R1P3)

The Inishbofin Island Focus Group suggested the color-coded warnings were not as informative as a physical description of the conditions expected:

> I think terminology is important, but I think people are far more inclined to heed stuff when they hear about gale force winds or storm force winds or expressions like that would cause far more [heed] than the color codes. And I know storm force winds, gale force winds from whatever direction, you certainly pay more heed to that and act on something like that before you will about an orange, red or whatever. (S4P3)

> I would think that the color-code system has lost its, its authority, I wanted to go for a better word. As S4P3 said there, the gale force, the storm force winds, that's what we would have grown up listening to. Like, you know if its storm force wind or violent storm force winds it's serious, rather than orange or red. It doesn't give specifics, whether it's 100 miles an hour or 50 miles an hour. At least the gale force and storm force winds are defined by their strength. (S4P4)

The message and risk posed by severe weather must be clear to motivate the appropriate response [35,67,69]. For many, these warnings lacked some clarity and necessary information concerning what actions to take, and as a result, there seemed to be less personalization, which lowered the chances of an individual taking appropriate action [49,70–72]. For weather warnings to be most effective, our findings emphasize the need to move away from a threshold-based weather warning system reporting only on the hydrometeorological conditions anticipated (e.g., low temperatures) to impact-based warnings, which highlight resulting conditions (e.g., slippery surfaces) [73,74]. Given participants' feelings of an incomplete understanding of the warnings, this move should enable a greater understanding of severe weather events than traditional systems [28].

While participants generally approved of the weather warning system, some participants from the Students, Agriculture, Marine Users, Dublin and Rural focus groups, as well as questionnaires respondents criticized the yellow warnings because the conditions they

represented were indistinguishable from typical bad weather:

Is there really a need to issue a yellow warning for a bit of rain? (QR547).

Most yellow are irrelevant or not worth worrying about (QR4671)

> I do find that sometimes the yellow weather warnings can [be too frequent]. I'm starting to ignore them because it just gives regular weather. (U1P4)

For some, the issuing of yellow warnings for what they regarded as usual Irish weather seemed to create frustration towards the entire weather warning system. The results suggest the threshold was viewed as too low, and thus the warnings were issued too frequently. Importantly, these warnings have utility for some users, e.g., farmers, and the challenge rests on how these warnings are communicated to different societal groups.

When a weather warning was issued, but the severe weather event did not materialize, some people suggested they ignore the following warnings, validating the limited number of empirical findings on the effects of false alarms [17,18]. These previous studies found evidence of false alarms related to specific warnings, such as tornadoes and low temperature events, however, our results suggest this is applicable to a range of warnings for various weather-related risks.

The theme of false alarms emerged in questionnaire responses and in five of the focus group discussions (Agriculture, Dublin, Inishbofin, Marine Users and 1st Rual focus groups), and was sometimes directly referenced as the "cry wolf" effect:

> For example, if an orange alert has been issued many times and you never have experience of anything happening then you get somewhat immune to hearing orange alert and neglect to hear it as the caution it is meant to be and may not take adequate preparations. Feels a little bit like a boy who cried wolf scenario (QR3282)

> Well, it means people, you know, the boy cried wolf thing. Even though intentions are good, if you've been warned about structural damage over and over again and whatever, and then and it's not happening, then you're going to get complacent. (S4P3)

For others, the "cry wolf" effect was implied:

> The yellow warning level alert is issued so frequently that people now ignore it and sometimes other alerts. (QR2296)

Constant yellow/orange rain warnings in Ireland are a bit of a joke so people just don't listen (QR2583).

Consistent with Mileti and Sorensen [49], the findings underscored the importance of believing that the message is accurate if individuals are to heed the warning. The results also contribute to a limited but growing number of empirical studies that demonstrate repeated false alarms can lead to a lack of confidence in a warning system and have negative impacts on their reactions [17,18,66,67]. This study's analysis confirmed that greater specificity of location and subsequent tailoring of messages could improve action [49,69,72]. This is not straightforward to accomplish as targeted impact-based warnings require ongoing collaboration between local people, the NMHS and other agencies to gather the necessary data on local impacts, geographical information, local vulnerabilities/exposures, and demographics etc. [25]. Advances in statistical models and data-driven approaches, including machine learning, could, however, make localized, tailored forecasting and messaging more achievable and improve future forecasts.

Regarding preparedness action, 34.3% (1326n) of survey respondents stated they would take action at an orange warning, with 55.4% (2143n) waiting until a red warning is issued before taking action. 6.3% (242n) reported they would have taken action at a yellow warning, and the remaining 160 individuals (4.1%) would not take any action on any warning. This data was used to examine preparedness in urban and rural dwellers. A variable ranging from zero to three summarized the warnings to which respondents reacted. It was defined as zero for individuals who did not react to any of the weather warnings, one for those who acted only on red, two for those who first reacted on an orange, and three for respondents who begin to prepare at a yellow. A higher value reflects that an individual acted in response to a less severe warning, which could be interpreted as indicating a higher degree of risk aversion. The overall average for this scale was 1.43. A chi-square test revealed a statistically significant association between action and urbanicity: $\chi 2$ (12df) = 34.819, $p < 0.001$. The average is slightly higher for rural dwellers (1.50) compared with city dwellers (1.37), indicating that rural dwellers are more likely to take action in response to lower-level warnings; perhaps pointing to a higher degree of risk aversion. While the difference was not large, an independent-samples *t*-test determined a statistically significant difference between the means ($t = 3.38$, $p = 0.001$). Finally, females on average take action in response to less severe warnings; indicating a higher degree of risk aversion. The average figure for females (1.47) was significantly different from that for males (1.32) on the basis of a *t*-test ($t = 5.82$, $p = 0.000$).

When discussing the two lower-level warnings, orange and yellow, most often associated with a snowstorm, focus group participants across all eight focus groups displayed a low threat appraisal, often reasoning that weather events would impact them minimally. This association supports the findings of Reynaud *et al.,* who found a significant association between threat appraisal and perceived flood probabilities. In our study, participant from all eight focus groups stated they would ignore such warnings entirely or described taking only minor protective measures [75]. For a yellow snow or ice warning, little action was taken except to remain vigilant in case the situation deteriorated. Some participants did not act immediately on orange warnings, with some participants from Dublin, Cork, Inishbofin, Marine Users, Students and 2nd Rural focus groups indicating they would ignore or disregard the warnings while others in the Cork, Dublin, Students and 1st Rural focus groups choose to "wait and see" how the situation might evolve:

> Probably just wait to see if it actually did snow, like, I'd wait for the evidence probably, and then make changes, if I need to do. (S1P4)

For an orange warning, others increased general alertness (discussed in all but the Inishbofin focus group), made changes to their driving behavior (Cork, Dublin, Marine Users focus groups), or prepared their home and garden (Agriculture, Cork, Students, and 2nd Rural focus group):

> I'd put my bins into the shed, I would secure any loose items from around the place. You know, obviously, just make sure that there was nothing lying around outside that could become a projectile in the wind. (R2P7)

> I'd possibly have a few bags of salts as well in the garage. (U2P1)

In contrast, participants in all focus groups outlined many specific changes in behavior and preparedness actions they would take in response to a red warning. The most common were gathering essential items and supplies which emerged in six of these focus groups (Agriculture, Cork, Dublin, Students and Rural focus groups), "Bread and milk and food to tide you over for two, two and a half, three days" (U2P1), avoiding leaving home and altering driving behavior (Agriculture, Cork, Dublin, Students and Rural focus groups), preparing for a loss of electricity, heating or water (Agriculture, Cork, Dublin, Students and 2nd Rural focus group), securing the home/garden/workplace (Agriculture, Inishbofin, Students and 2nd Rural focus group), and checking on vulnerable neighbors or relatives (Students and Cork):

> I just make sure I have things handy, torches and, you know, some kerosene lanterns and kerosene heaters, have mobile kerosene heaters, so those could kick in and, you know, we've put a lot of things in place in the house to be able to cope, at least for 48 hours. (R2P5)

Previous studies have shown threat appraisal to have a mixed effect on protection motivation [40,43]. Babcicky and Seebauer ([44]; p.1515) concluded "coping appraisal is strongly associated with protection motivation, threat appraisal is closely linked to non-protective responses. The effect of non-protective responses on protection motivation is negligibly small". However, our focus group participants highlighted that their protection motivation was driven by the formal threat appraisal, the red warning, issued by the NMHS, which resulted in their perception that they would be negatively impacted, thus the need to act. This contrasted with the findings of some previous studies, where coping appraisal dictated protective action [44,48,76,77]. A possible explanation for this difference could be the level of trust in the NMHS. Prior research in Ireland, using an online questionnaire of 6497 households in 2017, found that Met Éireann, the NMHS, was the second most trusted and acted upon source of information in an emergency, second only to the Emergency Services, with around 65% 'very likely' to act on their advice and a further 25% 'somewhat likely' [78]. Although this was not tested within the current study, the impact of trust could be a topic for further investigation.

Only in a very limited number of instances in our study was there evidence of a lack of a protective response because of a low coping appraisal (namely the high monetary costs) despite a high threat appraisal being present:

> Not much [preparedness actions taken before a Storm] because I only have a budget per-week, so couldn't really afford to stock up as much as I wished (QR2290)

3.4. Future weather service needs

Concerning future weather service needs, the overwhelming view of participants to emerge from all eight focus groups was the key services required from the NMHS were providing the most accurate weather prediction possible and warning of severe weather events. Participants also wanted more accurate localized forecasts (raised in the Agriculture, Inishbofin, Cork, Dublin, Marine Users and Rural focus groups), a more accurate long-term forecast (Marine Users, Agriculture and 1st Rural groups), downloadable GRIBs (Marine Users), reinstatement of the 3-h forecast (Agriculture group), and a forecast for fog (Dublin group).

The NMHS has developed a strong presence on social media; however, this success could become problematic as the volume of messages has become so vast as to irritate rather than inform some followers. The segmentation of social media feeds by topic, such as forecasts, warnings, be winter/summer-ready, and by user group, such as farmers, could help sustain successful engagement through social media [10] while reducing dissatisfaction with the current high volume of data.

Among students, there was a consensus that the NMHS catered for an older audience. This did not result in the students' disregarding warnings as they felt NHMS was reputable but showed a preference for forecasts provided by other organizations. They suggested increased engagement with younger people:

> For example, Ryanair's TikTok, you see a funny video, you click on the link, you look through the content. Next thing you know you're looking at flight prices. It's stuff like that you just engage with … I wouldn't search Met Éireann on Twitter to see like are they posting anything. (S1P6)

> It needs to be quick, easy, flashy, like if they want to keep their kind of reputation. Look, I know that they are very reputable already, but the generations to come might not think that. (S1P2)

Humor can be an effective tool in public messaging campaigns [79,80], and opportunities may exist to increase awareness of upcoming severe weather events using weather-related memes. There are many examples of such memes going viral in Ireland; examples at [81]. However, while humor can grasp public attention and build engagement [79], it can reduce the perceived severity of the issue being communicated [82] and may not promote preparedness action [80]. Further, the focus group data suggested that misplaced humor could reduce respect for the NMHS.

4. Conclusions

With a view to increasing national resilience, the purpose of this study was to determine what constitutes a user-centric weather forecasting and warning system for the Irish NMHS. The findings are summarized in Fig. 3 under the themes: forecasts, warnings, and household action.

A main limitation of this study was that participation was internet dependent. Volunteers were recruited using social media, the survey completed using an online platform and the focus groups conducted on Zoom. In-person focus groups and a paper-based postal survey could have reached a wider group.

4.1. Weather forecasts

Participants were influenced by weather forecasts when scheduling activities in their daily life, and especially when faced with work or safety concerns. The results confirm the significance and desire for accurate weather forecasts across all user groups.

Generally, participants exhibited low confidence in the accuracy of forecasts they received, most especially if the forecasted event was over three days out. Several participants, nevertheless, appreciated the uncertainty inherent in forecasting, and how this reduced as lead time reduced, supporting the findings by Morss *et al.* [7]. The findings also supported a move to probabilistic forecasting and the reporting of uncertainty data as an aid to effective decision making.

There was little indication that participants' use of forecasts decreased if they had low confidence in the forecast; instead, some participants expected inconsistent forecasts and used multiple sources to predict conditions. This finding mirrors the behavior identified by Mileti [35]; where people seek to verify the weather warning information received.

4.2. Perception and reaction to weather warnings

While the NMHS weather warning system was generally well-received, the perception that warnings are issued too frequently, challenging to understand, and lacking in accuracy reduced some people's confidence in the system. Color-coded warnings effectively portrayed a level of threat, especially for red warnings; however, the thresholds were not easily understood, which resulted in some users indicating that without an impact-based warning, they did not have a complete sense of the potential threat.

Focus group participants felt that an opportunity to link the warning to recommended preparedness actions was not being exploited. The high level of confidence in the NMHS and the prevalence of emergency information being sourced through the news media, gives the NMHS a powerful platform to influence emergency preparedness and action in Ireland.

Before acting on a warning, people must believe that the message is accurate, true, and applicable to them [35]. Our findings support this theoretical stance and highlight the importance of more localized warnings which take account of the variation in risk across a county and describe features of the threat using impact-based warnings. This was especially evident for an island community such as Inishbofin.

It seemed that low confidence in warnings lowered individuals' threat appraisals, which in turn reduced preparedness action. When discussing orange warnings, participants reported low threat appraisals, waiting to see how the situation unfolded before acting. Participants reported higher threat appraisals and greater preparedness action following a red warning. This suggested motivation to

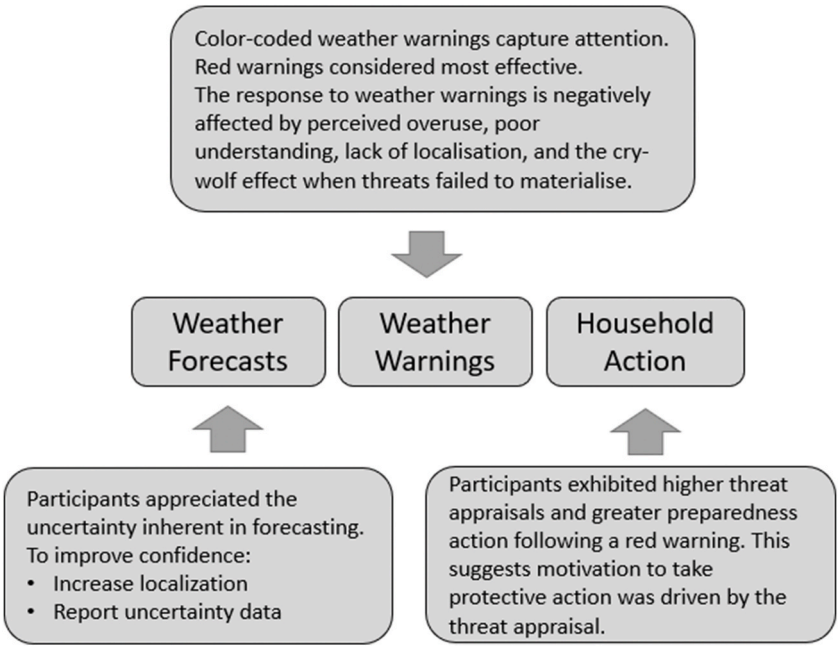


Fig. 3. Summary of findings.

take protective action was driven by threat appraisal. The factors driving these threat appraisals are worthy of further investigation.

While previous evidence for the cry-wolf effect was inconsistent, several focus group participants described this effect, some even citing the term cry-wolf, and suggested these false alarms impacted their reaction to subsequent warnings. To preserve confidence and avoid this cry wolf effect, when conditions change and the severe weather does not materialize as predicted, the reasons for this should be communicated by the NMHS. Moving to probabilistic forecasting and conveying uncertainty information will provide an opportunity to study the mitigating effect of clarity, transparency, and the publication of uncertainty data on the cry-wolf effect. We suggest that further research is required across different countries as national culture may influence factors such as the cry-wolf effect.

4.3. Future weather service needs

While the NMHS is well respected by the Irish public, who recognized its professionalism and expertise, there is a lack of awareness of the range of services it provides. As part of its renewed focus on a user-centric model of weather forecasts and warnings, the NMHS should improve communication and bottom-up engagement with local communities and publicize its core services. It was telling that new sections of the website and even the launch of the app was missed by many.

Participants wanted to see location-specific information updated hourly, and icons and percentages instead of text. For example, a "lite" version of the app, modelled on some of the more commercial providers, with increased emphasis on localization and icons could be developed. The more detailed app could be maintained for those with specialist needs.

Finally, the NMHS should encourage a feedback loop with service users. A variety of tools and techniques could be deployed to encourage feedback from users. These could include longitudinal surveys, service-user focus groups, comment upload point on website, and tracking of user feedback on social media sites. It was clear that the public had strong opinions about their services and strategy. Given the stereotypical view that Irish people talk about the weather constantly, and the prominent place of weather in Irish folklore and song, this came as no surprise.

Funding

This research was supported by the Irish Research Council and Met Éireann [COALESCE/2020/32].

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2023.103687.

References

[1] L.W. Uccellini, J.E.T. Hoeve, Evolving the national weather service to build a weather-ready nation: connecting observations, forecasts, and warnings to decision-makers through impact-based decision support services, Bull. Am. Meteorol. Soc. 100 (10) (2019) 1923–1942, https://doi.org/10.1175/BAMS-D-18-0159.1.

[2] WMO, Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services, World Meteorological Organization, 2015, p. 308. https://library.wmo.int/doc_num.php?explnum_id=3314.

[3] C.J. Fearnley, Standardising the USGS Volcano Alert Level System: Acting in the Context of Risk, Uncertainty and Complexity, Doctoral dissertation, University College London, 2011. https://discovery.ucl.ac.uk/id/eprint/1301994/.

[4] T. Loster, From the last mile to the first: risk awareness is the key, in: O. Edenhofer, J. Wallacher, H. Lotze-Campen, M. Reder, B. Knopf, J. Müller (Eds.), Climate Change, Justice and Sustainability, 2012, https://doi.org/10.1007/978-94-007-4540-7_23, 239–246.

[5] I. Kelman, M.H. Glantz, Early warning systems defined, in: A. Singh, Z. Zommers (Eds.), Reducing Disaster: Early Warning Systems for Climate Change, 2014, https://doi.org/10.1007/978-94-017-8598-3_5, 89–108 pp.

[6] Met Éireann, Ensemble Prediction Systems, 22 December 2021, 2021. Accessed 19th April 2022, https://www.met.ie/upgrade-to-met-eireanns-weather-forecast-system-april-may-2020.

[7] R.E. Morss, J.L. Demuth, J.K. Lazo, Communicating uncertainty in weather forecasts: a survey of the US public, Weather Forecast. 23 (5) (2008) 974–991, https://doi.org/10.1175/2008WAF2007088.1.

[8] S. Joslyn, S. Savelli, Communicating forecast uncertainty: public perception of weather forecast uncertainty, Meteorol. Appl. 17 (2) (2010) 180–195, https://doi.org/10.1002/met.190.

[9] L. Nadav-Greenberg, S.L. Joslyn, Uncertainty forecasts improve decision making among nonexperts, J. Cogn. Eng. Decis. Mak. 3 (3) (2009) 209–227, https://doi.org/10.1518/155534309X474460.

[10] T. Kox, L. Gerhold, U. Ulbrich, Perception and use of uncertainty in severe weather warnings by emergency services in Germany, Atmos. Res. 158 (2015) 292–301, https://doi.org/10.1016/j.atmosres.2014.02.024.

[11] R.H. Carr, B. Montz, K. Semmens, K. Maxfield, S. Connolly, P. Ahnert, R. Shedd, J. Elliott, Major risks, uncertain outcomes: making ensemble forecasts work for multiple audiences, Weather Forecast. 33 (5) (2018) 1359–1373, https://doi.org/10.1175/waf-d-18-0018.1.

[12] Met Éireann, Red & orange wind warnings ahead of storm Barra, Accessed 13th Feb 2023, https://www.met.ie/red-orange-wind-warnings-ahead-of-storm-barra, 2023.

[13] L.R. Barnes, E.C. Gruntfest, M.H. Hayden, D.M. Schultz, C. Benight, False alarms and close calls: a conceptual model of warning accuracy, Weather Forecast. 22 (5) (2007) 1140–1147, https://doi.org/10.1175/waf1031.1.
[14] K.M. Simmons, D. Sutter, False alarms, tornado warnings, and tornado casualties, Weather, Climate, and Society 1 (1) (2009) 38–53, https://doi.org/10.1175/2009WCAS1005.1.
[15] R. Meyer, H. Kunreuther, The Ostrich Paradox: Why We Underprepare for Disasters, University of Pennsylvania Press, 2017, p. 132.
[16] J.E. Walters, L.R. Mason, K. Ellis, B. Winchester, Staying safe in a tornado: a qualitative inquiry into public knowledge, access, and response to tornado warnings, Weather Forecast. 35 (1) (2020) 67–81, https://doi.org/10.1175/waf-d-19-0090.1.
[17] J.T. Ripberger, C.L. Silva, H.C. Jenkins-Smith, D.E. Carlson, M. James, K.G. Herron, False alarms and missed events: the impact and origins of perceived inaccuracy in tornado warning systems, Risk Anal. 35 (1) (2015) 44–56, https://doi.org/10.1111/risa.12262.
[18] J. LeClerc, S. Joslyn, The cry wolf effect and weather-related decision making, Risk Anal. 35 (3) (2015) 385–395, https://doi.org/10.1111/risa.12336.
[19] Met Éireann, December 2021, Met Éireann Warning System Explained, vol. 22, 2021. Accessed 19th April 2022, https://www.met.ie/met-eireann-warning-system-explained.
[20] A. Silver, Watch or warning? Perceptions, preferences, and usage of forecast information by members of the Canadian public, Meteorol. Appl. 22 (2) (2015) 248–255, https://doi.org/10.1002/met.1452.
[21] R.E. Morss, K.J. Mulder, J.K. Lazo, J.L. Demuth, How do people perceive, understand, and anticipate responding to flash flood risks and warnings? Results from a public survey in Boulder, Colorado, USA, J. Hydrol. 541 (2016) 649–664, https://doi.org/10.1016/j.jhydrol.2015.11.047.
[22] C.A. Williams, P.W. Miller, A.W. Black, J.A. Knox, Throwing caution to the wind: national weather service wind products as perceived by a weather-salient sample, Journal of Operational Meteorology 5 (9) (2017) 103–120, https://doi.org/10.15191/nwajom.2017.0509.
[23] A.L. Taylor, A. Kause, B. Summers, M. Harrowsmith, Preparing for Doris: exploring public responses to impact-based weather warnings in the United Kingdom, Weather, Climate, and Society 11 (4) (2019) 713–729, https://doi.org/10.1175/WCAS-D-18-0132.1.
[24] Met Éireann, Met Éireann strategy, Accessed 19th April 2022, https://www.met.ie/cms/assets/uploads/2017/08/Met_Eireann_Strategy_2017-2027.pdf, 2017.
[25] WMO, Guidelines on Multi-Hazard Impact Based Forecast and Warning Scenarios, World Meteorological Organization, 2015, p. 23. World Meteorological Organization, https://library.wmo.int/doc_num.php?explnum_id=7901.
[26] IFRC and UK Met Office, The Future of Forecasts: Impact-Based Forecasting for Early Action, 2020. Accessed 19th April 2022, https://www.forecast-based-financing.org/wp-content/uploads/2020/09/Impact-based-forecasting-guide-2020.pdf.
[27] I. Kelman, B. Ahmed, M. Esraz-Ul-Zannat, M.M. Saroar, M. Fordham, M. Shamsudduha, Warning systems as social processes for Bangladesh cyclones, Disaster Prev. Manag. 27 (2018) 370–379, https://doi.org/10.1108/dpm-12-2017-0318.
[28] S. Potter, S. Harrison, P. Kreft, The benefits and challenges of implementing impact-based severe weather warning systems: perspectives of weather, flood, and emergency management personnel, Weather, Climate, and Society 13 (2) (2021) 303–314, https://doi.org/10.1175/wcas-d-20-0110.1.
[29] A. Bostrom, R. Morss, J.K. Lazo, J. Demuth, H. Lazrus, Eyeing the storm: how residents of coastal Florida see hurricane forecasts and warnings, Int. J. Disaster Risk Reduc. 30 (2018) 105–119, https://doi.org/10.1016/j.ijdrr.2018.02.027.
[30] P. Weyrich, A. Scolobig, D.N. Bresch, A. Patt, Effects of impact-based warnings and behavioral recommendations for extreme weather events, Weather, Climate, and Society 10 (4) (2018) 781–796, https://doi.org/10.1175/WCAS-D-18-0038.1.
[31] M.A. Casteel, Communicating increased risk: an empirical investigation of the National Weather Service's impact-based warnings, Weather, Climate, and Society 8 (3) (2016) 219–232, https://doi.org/10.1175/WCAS-D-15-0044.1.
[32] D.S. Mileti, J.D. Darlington, The role of searching in shaping reactions to earthquake risk information, Soc. Probl. 44 (1) (1997) 89–103, https://doi.org/10.2307/3096875.
[33] M.A. Casteel, An empirical assessment of impact based tornado warnings on shelter in place decisions, Int. J. Disaster Risk Reduc. 30 (2018) 25–33, https://doi.org/10.1016/j.ijdrr.2018.01.036.
[34] R.E. Morss, C.L. Cuite, J.L. Demuth, W.K. Hallman, R.L. Shwom, Is storm surge scary? The influence of hazard, impact, and fear-based messages and individual differences on responses to hurricane risks in the USA, Int. J. Disaster Risk Reduc. 30 (2018) 44–58, https://doi.org/10.1016/j.ijdrr.2018.01.023.
[35] D.S. Mileti, Disasters by Design, Joseph Henry Press, 1999, p. 351.
[36] C. Fearnley, I. Kelman, Enhancing warnings Accessed 19th April 2022 2021. https://www.preventionweb.net/publication/enhancing-warnings.
[37] R.W. Rogers, S. Prentice-Dunn, in: D. Gochman (Ed.), Protection Motivation Theory, Handbook of Health Behavior Research: Vol. 1. Determinants of Health Behavior: Personal and Social, Plenum, New York, 1997, pp. 113–132.
[38] R. Zaalberg, C. Midden, A. Meijnders, T. McCalley, Prevention, adaptation, and threat denial: flooding experiences in The Netherlands, Risk Anal.: Int. J. 29 (12) (2009) 1759–1778. https://doi-org.dcu.idm.oclc.org/10.1111/j.1539-6924.2009.01316.x.
[39] P. Bubeck, W.J.W. Botzen, J.C. Aerts, A review of risk perceptions and other factors that influence flood mitigation behavior, Risk Anal.: Int. J. 32 (9) (2012) 1481–1495, https://doi.org/10.1111/j.1539-6924.2011.01783.x.
[40] J.K. Poussin, W.W. Botzen, J.C. Aerts, Factors of influence on flood damage mitigation behaviour by households, Environ. Sci. Pol. 40 (2014) 69–77, https://doi.org/10.1016/j.envsci.2014.01.013.
[41] R. Dittrich, A. Wreford, A. Butler, D. Moran, The impact of flood action groups on the uptake of flood management measures, Climatic Change 138 (3) (2016) 471–489, https://doi.org/10.1007/s10584-016-1752-8.
[42] J.S. Tang, J.Y. Feng, Residents' disaster preparedness after the Meinong Taiwan earthquake: a test of protection motivation theory, Int. J. Environ. Res. Publ. Health 15 (7) (2018) 1434, https://doi.org/10.3390/ijerph15071434.
[43] D.K. Twerefou, E. Adu-Danso, E. Abbey, B.D. Dovie, Choice of household adaptation strategies to flood risk management in Accra, Ghana, City and Environment Interactions 3 (2019), 100023, https://doi.org/10.1016/j.cacint.2020.100023.
[44] P. Babcicky, S. Seebauer, Unpacking Protection Motivation Theory: evidence for a separate protective and non-protective route in private flood mitigation behavior, J. Risk Res. 22 (12) (2019) 1503–1521, https://doi.org/10.1080/13669877.2018.1485175.
[45] N.K. Budhathoki, D. Paton, J.A. Lassa, K.K. Zander, Assessing farmers' preparedness to cope with the impacts of multiple climate change-related hazards in the Terai lowlands of Nepal, Int. J. Disaster Risk Reduc. 49 (2020), 101656, https://doi.org/10.1016/j.ijdrr.2020.101656.
[46] G.D. Brown, A. Largey, C. McMullan, P. Daffy, Fire safety protection motivation and preparedness in Irish apartments: a Post-Grenfell analysis, Saf. Sci. 148 (2022), 105630, https://doi.org/10.1016/j.ssci.2021.105630.
[47] M. Scovell, C. McShane, A. Swinbourne, Experience and the perceived efficacy of cyclone preparedness behaviour, International Journal of Disaster Resilience in The Built Environment 12 (2020) 70–183, https://doi.org/10.1108/ijdrbe-04-2020-0031.
[48] T. Grothmann, F. Reusswig, People at risk of flooding: why some residents take precautionary action while others do not, Nat. Hazards 38 (1) (2006) 101–120, https://doi.org/10.1007/s11069-005-8604-6.
[49] D.S. Mileti, J.H. Sorensen, Communication of Emergency Public Warnings: A Social Science Perspective and State-Of-The-Art Assessment, Department of Energy's, 1990, p. 162. https://www.osti.gov/servlets/purl/6137387.
[50] D. Mileti, Factors related to flood warning response, in: US-Italy Research Workshop on the Hydrometeorology, Impacts, and Management of Extreme Floods Perugia, 1995, p. 17. Italy, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.322.4179&rep=rep1&type=pdf.
[51] NRA, National Risk Assessment, 2020, Department of Defence, Ireland, 2020, p. 44, https://assets.gov.ie/128544/e3cf811b-8fc9-4fc6-ab4e-a70bd1fd423c.pdf.
[52] Met Éireann, An Analysis of Storm Emma and the Cold Spell Which Struck Ireland between the 28th of February and the 4th of March 2018, 2019. https://www.met.ie/cms/assets/uploads/2019/02/EmmaReport2019.pdf. (Accessed 27 January 2021).
[53] NDFEM, Review report on severe weather events 2017 - 2018. National directorate for fire and emergency management. https://www.gov.ie/en/publication/0c2e4-review-report-on-severe-weather-events-2017-2018/?referrer=http://www.housing.gov.ie/sites/default/files/publications/files/severe_weather_review_report_-_final.pdf, 2019. (Accessed 27 January 2021).
[54] CSO, Geographical Profiles of Income in Ireland 2016. Central Statistics Office, 2017. https://www.cso.ie/en/releasesandpublications/ep/p-gpii/geographicalprofilesofincomeinireland2016/incomeinireland/. (Accessed 12 March 2021).

[55] CSO, Census of Population 2016 - Profile 1 Housing in Ireland, Central Statistics Office, 2017, 12 March 2021, https://www.cso.ie/en/csolatestnews/pressreleases/2017pressreleases/pressstatementcensus2016resultsprofile1-housinginireland/.
[56] CSO, Urban and Rural Life in Ireland, Central Statistics Office, 2019, p. 12. March 2021, https://www.cso.ie/en/releasesandpublications/ep/p-urli/urbanandrurallifeinireland2019/introduction/#d.en.211130.
[57] M.Q. Patton, Qualitative Research and Evaluation Methods, Sage, Thousand Oaks, CA, 2002, p. 688.
[58] V. Braun, V. Clarke, Using thematic analysis in psychology, Qual. Res. Psychol. 3 (2) (2006) 77–101, https://doi.org/10.1191/1478088706qp063oa.
[59] V. Braun, V. Clarke, One size fits all? What counts as quality practice in (reflexive) thematic analysis? Qual. Res. Psychol. 18 (3) (2021) 328–352, https://doi.org/10.1080/14780887.2020.1769238.
[60] R.E.W. Pettifer, The development of the commercial weather services market in Europe: 1970–2012, Meteorol. Appl. 22 (3) (2015) 419–424, https://doi.org/10.1002/met.1470.
[61] A. Thorpe, The Weather Enterprise: A Global Public-Private Partnership, World Meteorological Organization, 2016. Accessed 19th April 2022, https://public.wmo.int/en/resources/bulletin/unnatural-disasters-communicating-linkages-between-extreme-events-and-climate.
[62] A.L. Taylor, T. Kox, D. Johnston, Communicating high impact weather: improving warnings and decision making processes, Int. J. Disaster Risk Reduc. 30 (2018) 1–4, https://doi.org/10.1016/j.ijdrr.2018.04.002.
[63] G. Gigerenzer, R. Hertwig, E. Van Den Broek, B. Fasolo, K.V. Katsikopoulos, A 30% chance of rain tomorrow": how does the public understand probabilistic weather forecasts? Risk Anal.: Int. J. 25 (3) (2005) 623–629, https://doi.org/10.1111/j.1539-6924.2005.00608.x.
[64] J. Handmer, B. Proudley, Communicating uncertainty via probabilities: the case of weather forecasts, Environ. Hazards 7 (2) (2007) 79–87, https://doi.org/10.1016/j.envhaz.2007.05.002.
[65] T. Kox, H. Kempf, C. Lüder, R. Hagedorn, L. Gerhold, Towards user-orientated weather warnings, Int. J. Disaster Risk Reduc. 30 (2018) 74–80, https://doi.org/10.1016/j.ijdrr.2018.02.033.
[66] J.E. Losee, S. Joslyn, The need to trust: how features of the forecasted weather influence forecast trust, Int. J. Disaster Risk Reduc. 30 (2018) 95–104, https://doi.org/10.1016/j.ijdrr.2018.02.032.
[67] S.E. DeYoung, J.N. Sutton, A.K. Farmer, D. Neal, K.A. Nichols, Death was not in the agenda for the day": emotions, behavioral reactions, and perceptions in response to the 2018 Hawaii Wireless Emergency Alert, Int. J. Disaster Risk Reduc. 36 (2019), 101078, https://doi.org/10.1016/j.ijdrr.2019.101078.
[68] M.M. Wood, D.S. Mileti, H. Bean, B.F. Liu, J. Sutton, S. Madden, Milling and public warnings, Environ. Behav. 50 (5) (2018) 535–566, https://doi.org/10.1177/0013916517709561.
[69] D. Rogers, V. Tsirkunov, Implementing Hazard Early Warning Systems, vols. 11–03, GFDRR WCIDS Report, 2011, p. 47. https://www.preventionweb.net/files/24259_implementingearlywarningsystems1108.pdf.
[70] UNISDR, Global Survey of Early Warning Systems: an Assessment of Capacities, Gaps and Opportunities toward Building a Comprehensive Global Early Warning System for All Natural Hazards, United Nations, 2006, p. 56. https://www.preventionweb.net/files/3612_GlobalSurveyofEarlyWarningSystems.pdf.
[71] T. Vihalemm, M. Kiisel, H. Harro-Loit, Citizens' response patterns to warning messages, J. Contingencies Crisis Manag. 20 (1) (2012) 13–25, https://doi.org/10.1111/j.1468-5973.2011.00655.x.
[72] C.B. Mayhorn, A.C. McLaughlin, Warning the world of extreme events: a global perspective on risk communication for natural and technological disaster, Saf. Sci. 61 (2014) 43–50, https://doi.org/10.1016/j.ssci.2012.04.014.
[73] R. Kaltenberger, A. Schaffhauser, M. Staudinger, What the weather will do"–results of a survey on impact-oriented and impact-based warnings in European NMHSs, Adv. Sci. Res. 17 (2020) 29–38, https://doi.org/10.5194/asr-17-29-2020.
[74] WMO, Multi-hazard Early Warning Systems: A Checklist, World Meteorological Organization Doc., 2018, p. 20. https://library.wmo.int/doc_num.php?explnum_id=4463.
[75] A. Reynaud, C. Aubert, M.H. Nguyen, Living with floods: protective behaviours and risk perception of Vietnamese households, Geneva Pap. Risk Insur. - Issues Pract. 38 (3) (2013) 547–579, https://doi.org/10.1057/gpp.2013.16.
[76] P. Bubeck, W.J. Botzen, H. Kreibich, J.C. Aerts, Detailed insights into the influence of flood-coping appraisals on mitigation behaviour, Global Environ. Change 23 (5) (2013) 1327–1338.
[77] S. Odidi, S. Tantanee, K. Nusit, P. Buranajarukorn, Factors influencing the uptake of flood mitigation measured in budalangi, Kenya, Geogr. Tech. 15 (2020) 80–90, https://doi.org/10.21163/gt_2020.151.07.
[78] C. McMullan, A. Largey, G.D. Brown, Weather & climate-related risk perception and household preparedness. http://doras.dcu.ie/26063/, 2020. (Accessed 12 February 2023).
[79] A. Gough, R.F. Hunter, O. Ajao, A. Jurek, G. McKeown, J. Hong, E. Barrett, M. Ferguson, G. McElwee, M. McCarthy, F. Kee, Tweet for behavior change: using social media for the dissemination of public health messages, JMIR Public Health and Surveillance 3 (1) (2017) e6313, https://doi.org/10.2196/publichealth.6313.
[80] J.D. Fraustino, L. Ma, CDC's use of social media and humor in a risk campaign—"Preparedness 101: zombie Apocalypse", J. Appl. Commun. Res. 43 (2) (2015) 222–241, https://doi.org/10.1080/00909882.2015.1019544.
[81] Extra, The seven funniest Irish weather moments in 10 years, DMG Ireland 12 (2021). January 2022, https://extra.ie/2021/01/09/must-see/funniest-irish-weather-moments-10-years.
[82] E. Moyer-Gusé, C. Mahood, S. Brookes, Entertainment-education in the context of humor: effects on safer sex intentions and risk perceptions, Health Commun. 26 (8) (2011) 765–774, https://doi.org/10.1080/10410236.2011.566832.