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A multidisciplinary investigation of Storms Ciara and Dennis, February 2020

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ABSTRACT

High magnitude storms have periodically impacted the communities of Western Britain and this storm threat is predicted to increase with climate change. Understanding the factors that contribute to storm catastrophe is essential to mitigate the effects of future storms. This multidisciplinary study collectively analyses meteorological, tidal gauge and newspaper data from Storms Ciara and Dennis in February 2020 to assess the environmental, social and political impacts and causes of the catastrophe in Western Britain. The analysis shows that although the storm period comprising Ciara and Dennis was a meteorological climate anomaly and short-term local authority and community responses were effective, shortcomings in governmental policies likely enhanced storm impacts. The study findings suggest that substantive changes to UK government coastal and fluvial management policies and the wider long-term climate change strategy are required to address climate change risk and reduce community storm vulnerability in Western Britain. The key roles of the media in enhancing public hazard preparedness and raising awareness of the impacts of climate change catastrophes and the wider climate crisis are exhibited. A multidisciplinary mixed methods analysis combining quantitative meteorological and tidal data, qualitative newspaper data and peer-reviewed research is shown to identify the likely cause of catastrophe and can inform future climate change vulnerability mitigation.

1. Introduction

Climate change is predicted to increase the frequency of high magnitude storms throughout the UK and Western Europe in the twenty-first century [1,2]. Climate and weather records are being more frequently broken, and the British population is suffering more regularly from the destruction and degradation of the built and natural environments (Masselink et al., 2020; [3,4]. The winter of 2019–20 represents a key example, as regions across the UK were impacted by storms and flooding. The UK had the wettest February since records began (1862), with a monthly mean total precipitation of 209.1 mm, which was 237% greater than the 1981–2010 February baseline [5]. The Meteorological (Met) Office identified six named storms in this period, defined as events which were predicted to have a likely significant impact on the UK and potentially pose a risk to human life [6].

Of the six storms that produced the exceptionally stormy winter, Storms Ciara and Dennis had the greatest consequences for the UK [7]. Ciara struck the UK on February 8–9, bringing high winds and very heavy rain and resulted in an estimated £200 m of insured losses (*The Guardian*, 17:05 February 14, 2020). Storm Dennis subsequently hit the UK between February 14–16. A record 594 UK flood warnings and alerts were issued with the worst suffering occurring in the Rhondda Valley, South Wales where 800 homes were

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evacuated (*The Guardian*, 20:05 February 16, 2020). The storms prompted major community, local authority (LA) and national government responses designed to predict, prevent, mitigate and recover from the events. Despite the high storm magnitude, the damage and destruction were partially attributed to UK government failings (e.g. [8] *The Guardian*, 13:25 February 17, 2020; *The Observer*, 06:12 February 23, 2020).

The 2019/20 winter and the two storms have been analysed from a primarily meteorological perspective [7,9], while [10] stated that the storms highlighted the need to adapt legal frameworks to promote community adaptation to more frequent future flooding. However, no study has collectively analysed the diverse factors which contributed to the catastrophe. This multidisciplinary research, therefore, employs a mixed methods approach to better understand the characteristics, causes and impacts of Storms Dennis and Ciara in Western Britain in February 2020. By combining the disciplines of environmental science and environmental history, the study employs a mixed methods approach utilising meteorological, tidal gauge and newspaper (*The Guardian* & *The Observer*) data to analyse the storm period comprising both Storm Ciara and the subsequent Storm Dennis. The storm period is defined as between 00:00 February 4 to 00:00 February 19, while the newspaper information directly relating to the storm period that was published until February 23 is also analysed.

Wind speed, precipitation and storm surge data as well as newspaper data concerning the storm impacts, short-term community and State (local authorities and national governments) response as well as long-term government policies are examined. The key roles of the media in public hazard and early warning communication as well as in enhancing awareness of the impacts of the climate change crisis are also considered. [11]; p.1) states that 'our actions turn natural hazards into catastrophes' while [12]; p.1) notes that natural hazards are not unfortunate unpreventable disasters and instead are catastrophes resulting from 'the intersection of natural hazards … with human populations in varying states of economic, social, and cultural vulnerability'. This research, therefore, examines to what extent meteorological variability, short-term response and long-term policies contributed to the catastrophe of Storms Dennis and Ciara. The study underlines the importance of multidisciplinary research in improving the understanding of extreme weather events and exhibits the diverse factors that cause catastrophe.

2. Material and methods

To examine the meteorological characteristics, human impacts and State and community responses to the storms, a mixed methods approach using quantitative and qualitative data was adopted. Previous research has highlighted the considerable contribution of multidisciplinary approaches combining quantitative and qualitative data to improving the understanding of climate events. Chaumillion et al.*'s* [13] research review exhibited how multidisciplinary studies incorporating tidal, meteorological and sedimentological data with historical archives including naval reports, newspapers and academic publications have originally improved the understanding of storms and coastal flooding worldwide. Such understandings are shown to offer key contributions to management and mitigation. More specifically [14] integrated newspaper data (including relayed social media), weather observations and climate model downscaling to analyse the impacts of extreme weather events in Nome, Alaska from 1990 to 2018. This multidisciplinary research exhibited how previous storm impacts centred on transportation, community activities and utilities were frequently associated with high wind, extreme low temperatures, heavy snowfall events, and winter days above freezing. By further considering predicted climate change and extreme weather trends, the findings provided a broad insight into how extreme-weather impacts could change throughout the twenty-first century with key implications for climate adaptation planning [14]. More broadly the IPCC sixth assessment report also notes that multidisciplinary research should play an increasingly important role in management processes as it demonstrates the interconnected impacts of hazards and could ultimately influence whether communities and the environments they often depend upon appropriately adapt to increasing climate threats [15]. This paper therefore employs a multidisciplinary approach to exhibit how analyses combining quantitative weather data, qualitative newspaper reports and wider peer-reviewed research can offer an important and original contribution to improving the understanding of climate hazards, impacts and their causes.

The paper analyses the overall storm period collectively comprising the two storms but also acknowledges the differences between Ciara and Dennis. Western Britain was selected as the spatial focus as the area and its population is predicted to become increasingly vulnerable to storm and storm surge threats due to 21st century climate change while when storm and surge research is considered the area is also under researched compared to Eastern Britain primarily due to the legacy of the 1953 flood [16–18]. The quantitative data comprised meteorological and tidal gauge records collected from eight and seven stations respectively to exhibit storm variability (see Figs. 1 and 2).

The meteorological storm data comprised of hourly wind speed (ms^{-1}) and precipitation (mm) records observed at Met Office stations and sourced from the Centre for Environmental Data Analysis (CEDA) archives. Wind speed and precipitation were selected as the majority of storm damage in the UK results from these factors [19,20]. The selected sites were: Stornoway, Bishopton, Blackpool, Valley (Anglesey), Aberporth, Chivenor and Camborne (see Fig. 1). Data from Usk, Monmouthshire were included as it was the closest station with available data to the highly impacted Rhondda Valley; however, only precipitation data were available. The only dataset anomaly was a short period of no data for Chivenor from 10:00 10/02 till 09:00 11/02. Sites at the closest proximity to the tidal gauges were selected to assess meteorological and storm surge correspondence.

Tidal gauge data were selected to indicate storm surge magnitude variability as surges have resulted in great loss in coastal areas [21]; Haigh et al., 2016). The tidal gauge data comprised storm surge heights measured at 00:15 intervals (highest available) at seven tidal gauges from 00:00 February 04, 2020 to 00:00 February 19, 2020. Storm surge height (residual) at each gauge was calculated by the British Oceanic Data Centre (BODC) by subtracting observed and predicted tidal height. Data were sourced from the BODC (2022) archives [22]. Surge residual was used as opposed to skew as the research looked to analyse all the magnitude variability and reported storm surge impacts. The research approach took into account that substantial variability and multiple impacts could occur during a

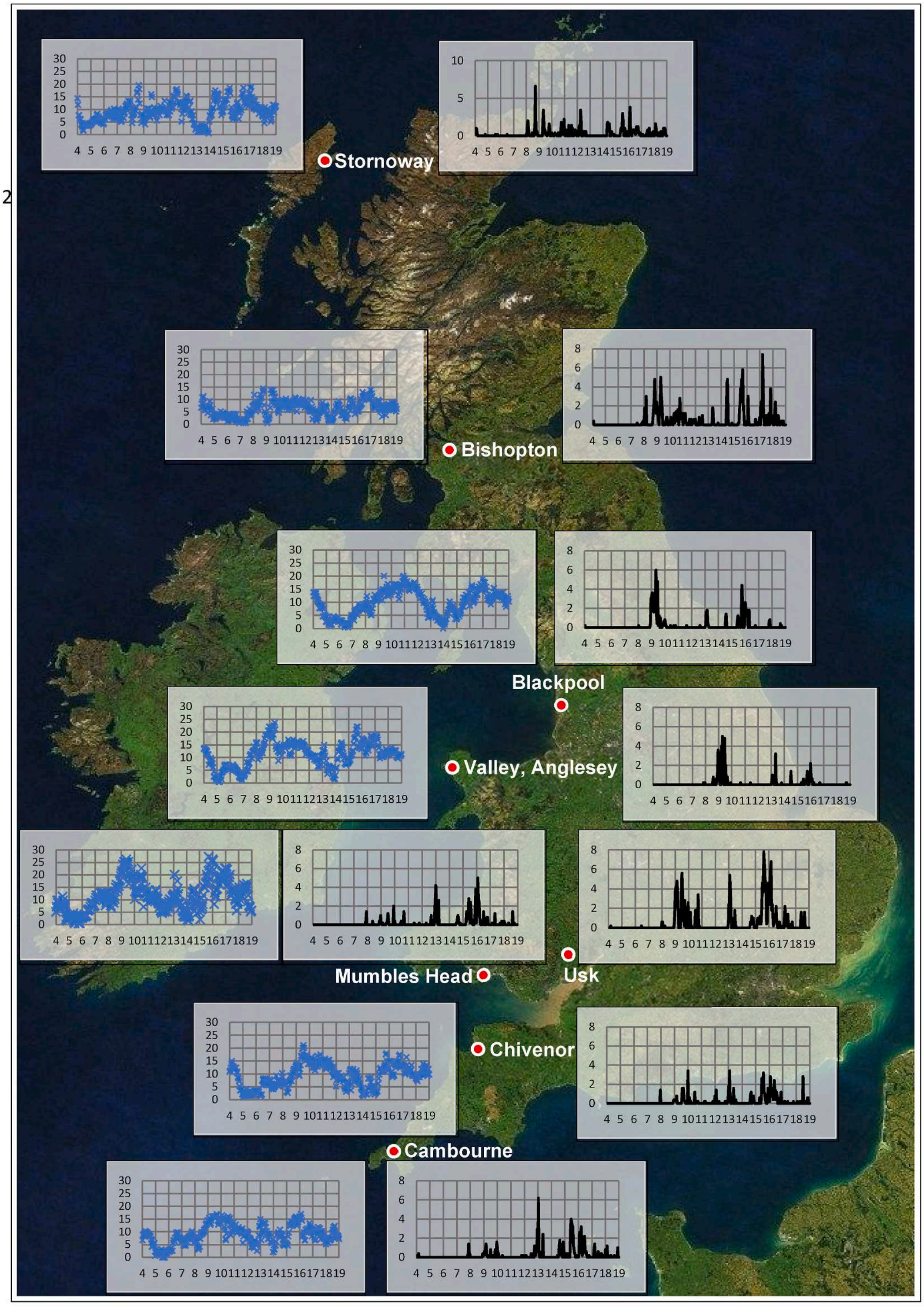

Fig. 1. Wind speed (light blue scatter) and precipitation (black line) variability for Storms Dennis and Ciara at the seven Meteorological Office stations. Data were collected at 01:00 intervals from 00:00 February 4 to 00:00 February 19. For wind speed graphs, wind speed (ms^{-1}) is shown on the y axis. For precipitation graphs, precipitation (mm) is shown on the y axis. The x axis represents time (date). Data were sourced from the Centre for Environmental Data Analysis archives.

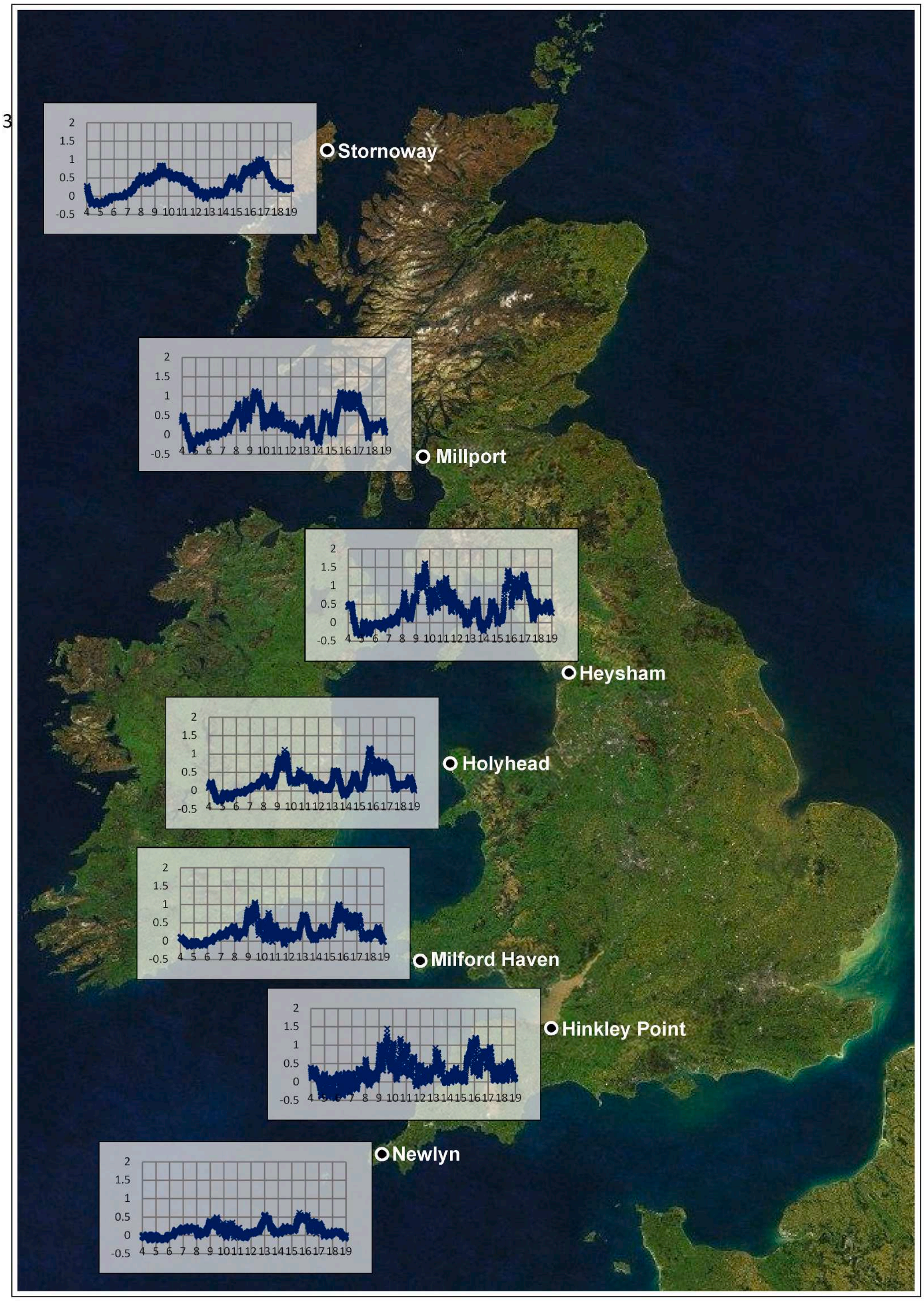

Fig. 2. Storm surge height variability for Storms Dennis and Ciara at the seven tidal gauges. Data were collected at 00:15 intervals from 00:00 February 04, 2020 to 00:00 February 19, 2020. The y axis represent storm surge height (m) and data were supplied by the BODC. Surge height (residual) was calculated by the BODC by subtracting observed from predicted tidal heights (predicted). The x axis represent time (date).

12 h and 25 min tidal cycle. Given there is only one skew reading per tidal cycle, using residual readings reported at 00:15 intervals was therefore more appropriate [23].

The gauges were located at: Stornoway, Millport, Heysham, Holyhead, Milford Haven, Hinkley Point and Newlyn (see Fig. 2). The distribution of the gauges indicated storm surge magnitude variability throughout Western Britain. To indicate relative storm surge magnitude, the maximum recorded storm surges (Storms Ciara and Dennis) were ranked against the monthly maximum surge recordings (BODC data) at each station from January 1990 to March 2022 (267 readings). At the Hinkley Point maximum monthly readings were from May 1990 to March 2022 (263 readings). The maximum recorded value during February 2020 which always occurred within the storm window (i.e. between February 4 and February 19), was indicated along with the corresponding storm and maximum monthly rank. For the storm with the lower maximum surge magnitude, which was not recorded in the BODC maximum monthly surge dataset, the calculated rank is given relative to the monthly maximum. Meteorological (wind speed and precipitation) and tidal gauge (storm surge residual) data were selected as variables so that the data from different sites could be best objectively compared in order to appraise spatial differences in storm duration and magnitude variability. The three data categories wind speed, precipitation and storm surge residual variables had comprehensive data sets and statistical climate data for all sites reaching back to 1990 and 1991 respectively. These datasets therefore enabled the accurate comparison and ranking of the individual storms and storm period relative to regional climates and past events.

To analyse the human impacts as well as the community and State storm response, newspaper data from *The Guardian* online were identified. These newspaper data also included information from *The Observer* and *The Guardian Weekly*, which are owned by *The Guardian* Media Group. The national compact newspapers were chosen as they feature detailed information on local and national storm impacts as well as scientific information [24,25]; Archer et al., 2019). *The Guardian* was selected as it represents a high circulation British compact newspaper with the greatest environmental focus and is generally considered less constrained by commercial or political bias than most other major UK newspapers [26,27]. The analysis identified relevant media content through purposive sampling, following [28]. Articles were identified using the Google™ search engine and a broad Boolean search-string adapted to locate relevant articles from *The Guardian* online. This approach has been successfully undertaken in other studies examining media reporting and representations of weather and climate change (e.g. Refs. [29–31]. The search string was designed to identify articles relevant to the storm period and required articles to include either: 'storm' or 'flood' and 'Dennis' or 'Ciara' as keywords. The period February 4 to February 23 was selected to capture all published information directly relating to the storms and their effects. After February 23, reports specifically relating to the two storms ceased. The tailored search returned 32 online articles plus two live feeds pages (one live feed for each storm) for the entire storm period comprising Storms Ciara and Dennis. The articles provided detailed insights into the meteorological characteristics, impacts, direct responses and wider (including long-term) repercussions and responses to the storm period. Articles drew on information from sources including first-hand community witnesses, emergency services, senior governmental (and shadow) ministers and scientists providing a wide perspective on the storms.

The analysis of the storm reports focused on the correspondence of scientific storm variability with the storm impacts, immediate community and State responses as well as the role of long-term government policies regarding severe weather and climate change. Storm magnitude variability as exhibited by the scientific data was firstly analysed. The correspondence between the scientific data and the reported impacts and responses was then examined. The discussion subsequently draws on wider research to assess the factors that contributed to the catastrophe.

3. Results: meteorological and tidal gauge

The results are divided into two sections for meteorological and tidal gauge data spanning the storm period from 00:00 February 4 to 00:00 February 19. This scientific data are subsequently analysed with the storm reports from *The Guardian* and *The Observer* in section 8.4. Where the factors that contributed to the catastrophe are analysed.

3.1. Meteorological data

The hourly Met Office meteorological data gathered from the CEDA archives exhibit variability in precipitation and wind speed (Table 1 and Fig. 1). The maximum hourly precipitation of 7.8 mm was recorded at Usk at 15:00 on February 15, 2020 during Storm Dennis. Mean hourly precipitation during the storm period was highest at Usk (0.51 mm) and lowest at Valley (0.14 mm). The lowest total hours of rainfall were also recorded at Valley (54 h) while Stornoway had the greatest (149 h). Total precipitation during the

Table 1

Precipitation statistics for the seven sites between 00:00 04/02 to 00:00 19/02. For precipitation (mm), maximum hourly amount, mean, hours of rainfall and total precipitation are shown. For comparison the mean total precipitation adjusted for a 15 day period (equal length) in the month of February from 1991 to 2020 is displayed along with differences between the storm period in mm and %. The 15 day period value is calculated from Ref. [6] mean February total precipitation data assuming an average day length of 28.27 which accounts for the eight leap years (29 day months) during the period.

Site Location	Precipitation (mm)						
	Storm Period				1991–2020 Comparison		
	Maximum Hourly Amount	Mean	Hours of Rainfall	Total Precipitation	Mean Total Precipitation (15 Da y)	Δ	Δ (%)
Stornoway	6.6	0.32	149	113.8	59.4	54.4	91.7
Bishopton	7.4	0.46	140	165.8	66.3	99.5	150.0
Blackpool	6.0	0.23	61	82	33.9	48.1	141.5
Valley	5.0	0.14	54	51.2	32.9	18.3	55.6
Mumbles Head	5	0.20	78	71	39.1	31.9	81.6
Usk	7.8	0.51	108	190.6	49.9	140.7	282.3
Chivenor	3.4	0.20	91	72.4	37.0	35.4	95.7
Camborne	6.2	0.27	100	90	50.2	39.8	79.3

storm period was highest at Usk (190.6 mm) and lowest at Valley (51.2 mm). Relative to the mean total precipitation for a 15 day period in February (1991–2020), Usk also received the greatest total rainfall increase at 140.7 mm (282.3%). The value at Usk was 132.3% greater than the second highest of 150.0% at Bishopton. Valley had the smallest increase relative to the mean total precipitation in a 15 day period in February at 18.3 mm and 55.6%.

Wind speed was measured at hourly intervals at seven Met Office stations. Statistical variability concerning maximum, mean and number of hours of wind speed ≥ Force 7 were considered. Force 7 (13.9 ms^{-1}) was selected as this is classified as a moderate gale on the Beaufort Scale was the original scientific quantitative classification of a gale still used in the UK [4].

The greatest maximum wind speed of 27.3 ms^{-1} (Force 10) was recorded at 17:00 on February 15, 2020 at Mumbles Head (Table 2). The lowest maximum wind speed of 14.4 ms^{-1} was recorded at Bishopton at 18:00 on February 08, 2020. Bishopton also experienced the shortest period (1 h) when a wind speed ≥ Force 7 was recorded. The greatest number of hours when wind speed was ≥ Force 7 were recorded at Mumbles Head (106 h) and Valley (103 h). Mean wind speed over the 15 day period was also greatest at Mumbles Head (11.3 ms^{-1}) with Valley second (11.2 ms^{-1}). Bishopton had the lowest mean wind speed of 6.3 ms^{-1}. Compared to the mean wind speed recorded in February from 1991 to 2020, Mumbles Head and Valley exhibited the greatest absolute difference with the mean wind speeds during the storm period at 4.0 ms^{-1} greater than the 1991–2020 February mean. The lowest difference in mean wind speed was observed at Stornoway (1.9 ms^{-1}) which was also the smallest percentage difference relative to the 1991–2020 mean (26.8%). At Blackpool, the mean wind speed percentage was 62.3% (3.7 ms^{-1}) greater than the 1991–2020 February mean which was the greatest percentage increase.

3.2. Tidal gauge data

The BODC tidal gauge data exhibit the variability in storm surge maximum magnitude at the seven sites at 00:15 intervals throughout Western Britain. The maximum surge during each storm was the main variable considered as the mean surge readings can be distorted by changes in wind direction relative to coastlines and gauges. The greatest storm surge height was recorded at Heysham during Storm Ciara at 15:45 on February 09, 2020 measuring 1.610 m, ranking as the 21st greatest monthly maximum surge recorded at Heysham between January 1990 to March 2022 (21/267). The second greatest storm surge of 1.458 m was recorded at Hinkley Point during Storm Ciara at 12:15 on February 09, 2020. This ranked as the 14th greatest station monthly maximum recorded from May 1990 to March 2022 (14/263). The greatest storm surge recorded during Storm Dennis of 1.409 m was observed at Heysham at 18:45 on February 15, 2020 which was equivalent to the 32nd greatest site monthly maximum surge (Table 3).

The lowest maximum storm surge magnitude for Dennis and Ciara was recorded at Newlyn, the only east facing gauge. A maximum surge height of 0.616 m (13:30 February 15, 2020) was recorded ranking as the 30th greatest maximum monthly surge recorded at Newlyn (January 1990 to March 2022). For Storm Ciara a maximum surge height of 0.493 m was recorded at Newlyn, equivalent to the 83rd greatest maximum monthly surge (Table 3).

When overall storm surge magnitude maximum monthly rank is considered, the greatest surges were recorded during Storm Dennis at Stornoway (1.009 m) and Holyhead (1.159 m) which both ranked 4/267. The greatest calculated equivalent storm surge magnitude monthly rank was recorded at Holyhead during Ciara at 13:00 February 09, 2020 which was 10/267. The smallest overall maximum surges for both observed and equivalent monthly rank were at Newlyn ranking 30/267 and 83/267.

4. Discussion and analysis

This section analyses the scientific storm data and the 34 newspaper articles concerning the impacts and effects of Storms Ciara and Dennis. It considers to what extent the catastrophe was a result of meteorological and surge variability, short-term LA and community response and long-term government policy. The short-term response refers to the immediate response during the storm period including the issuing of forecasts, the preventative actions of the Environment Agency (EA) and the LA storm response. Long-term policy refers to the influence of wider relevant governmental policies during the storms and on other extreme climate events.

Table 2

Wind speed statistics for the seven sites between 00:00 04/02 to 00:00 19/02. For wind speed (ms^{-1}), maximum wind speed, hours when wind speed was ≥ Force 7 (13.9 ms^{-1}) and mean are exhibited. For comparison, the mean February wind speed from 1991 to 2020 is displayed along with differences in ms^{-1} and %.

Site Location	Wind Speed (ms^{-1})					
	Storm Period			1991–2020 February Comparison		
	Max Wind Speed	Hours ≥ Force 7 (13.9 ms^{-1})	Mean	Mean	Δ	Δ (%)
Stornoway	19.5	42	9.2	7.3	1.9	26.8
Bishopton	14.4	1	6.3	4.5	1.8	40.8
Blackpool	20.1	78	9.8	6.0	3.7	62.3
Valley	23.7	103	11.2	7.2	4.0	55.5
Mumbles Head	27.3	106	11.3	7.3	4.0	54.8
Chivenor	21.1	53	9.3	5.9	3.3	55.9
Camborne	17.0	42	9.0	6.1	2.8	45.8

Table 3
Maximum storm surge magnitude statistics for Storms Ciara and Dennis. The rank of the maximum surge recorded in both storms is given relative to monthly maximum surge recordings at each station from January 1990 to March 2022 (267 maximum monthly readings). Hinkley Point readings are from May 1990 to March 2022 (263 readings). The maximum recorded value within the month of February 2020 is given along with the corresponding storm. Given the maximum monthly value can only correspond with either Dennis or Ciara, for the storm with the lower maximum magnitude (i.e. not recorded as a monthly max) the surge magnitude and equivalent calculated rank (*) is given relative to monthly maximums.

Gauge Location	Date	Time	Overall Observed Height (m AD)	Surge Height (m)	Storm	Max Surge Monthly Rank
Stornoway	February 16, 2020	18:30:00	2.741	1.009	Dennis	4
Stornoway	February 09, 2020	13:00:00	1.560	0.832	Ciara	15*
Millport	February 09, 2020	09:15:00	3.540	1.123	Ciara	29
Millport	February 15, 2020	16:45:00	4.665	1.104	Dennis	32*
Heysham	February 09, 2020	15:45:00	4.375	1.610	Ciara	21
Heysham	February 15, 2020	18:45:00	7.113	1.409	Dennis	32*
Holyhead	February 15, 2020	17:45:00	4.726	1.159	Dennis	4
Holyhead	February 09, 2020	13:00:00	4.719	1.115	Ciara	10*
Milford Haven	February 09, 2020	12:15:00	1.808	1.052	Ciara	16
Milford Haven	February 15, 2020	16:45:00	2.529	1.003	Dennis	23*
Hinkley Point	February 09, 2020	14:30:00	3.867	1.448	Ciara	14
Hinkley Point	February 15, 2020	16:45:00	2.529	1.003	Dennis	23*
Newlyn	February 15, 2020	13:30:00	3.033	0.616	Dennis	30
Newlyn	February 09, 2020	11:30:00	1.224	0.493	Ciara	83*

4.1. Impending storm

The Met Office issuing of UK-wide wind warnings a day after the identification of a deep low pressure system in the North Atlantic on February 4 represented the first storm recognition [32]. The Met Office warnings sought to initially raise awareness to heighten short-term community, LA and government storm preparedness. On February 4 the scientific data exhibited comparatively low precipitation at most sites with a daily hourly maximum of 1 mm (02:00) and total of 3 mm at Stornoway. Windspeed at most sites was also low in the context of the period with hourly wind speed reaching highs of 14.4 ms^{-1} and 14.9 ms^{-1} at Stornoway (00:00) and Chivenor (04:00). Storm surge magnitude daily maximums of 0.502 m and 0.522 m were also recorded at Millport (02:00) and Heysham (04:45) (temporal trends of data are summarised in Fig. 7). The coming storm was not reported in *The Guardian*. The naming of the Storm Ciara by the Met Office on February 5 designated the likely high impact and showed the first attempt to communicate the impending threats [5]. As Met Office storm naming enhances public engagement and enables quicker information dissemination (Charlton-Perez et al., 2019), the storm naming represents a clear attempt to heighten threat awareness and preparedness.

Despite clear warnings, *The Guardian* did not feature any storm-specific articles until February 8 although an article primarily focused on the English Channel migrant crisis noted the rough seas created by the pre-storm conditions while a sporting article stated the storm was likely to be the 'UK's strongest storm since 2012' (*The Guardian*, 18:44 February 7, 2020; *The Guardian*, 22:00 February 7, 2020). The scientific data for February 7 reflected the coming storm as magnitude increased at most sites. Hourly wind speed maximums of 15.9 ms^{-1} (23:00) and 13.4 ms^{-1} (20:00) were noted at Valley and Stornoway and storm surge magnitude increased with maxima of 0.540 m (21:00) and 0.509 m (23:30) at Millport and Stornoway. Precipitation increased more abruptly with the greatest hourly rainfall of 1.4 mm at Mumbles and Chivenor (23:00) and Camborne (21:00).

4.2. Storm Ciara

On February 8 an article was published featuring a combination of warnings detailing likely storm magnitude, spatial extent and tangible impacts (*The Guardian*, 12:36 February 8, 2020). Met Office public information was communicated and the chief forecaster was quoted as stating the UK was 'covered with yellow wind warnings, which means gusts of 50–60 mph regardless of where you are'. Public storm impacts were also highlighted by different governmental organisations e.g. Network Rail. The information from governmental agencies demonstrated clear pre-emptive efforts to enhance threat awareness and public communication. Storm naming and the use of colour-coded warnings exemplified this as both enable the public to use heuristic processing (i.e. simplified learning) to understand storm severity and threat [33].

The increasing storm threat and magnitude during the evening of February 8 and February 9 were indicated by the data (Fig. 7). Wind speed was greatest as Mumbles and Valley on February 9 as the mean windspeeds were 22.0 ms^{-1} and 16.3 ms^{-1} compared to the 1991–2020 February mean of 7.3 ms^{-1} and 7.2 ms^{-1}. Mean windspeeds were therefore 201.7% and 126.4% greater, rendering them considerable weather anomalies. Storm surges of 1.610 m (15:45), 1.448 m (14:30), 1.115 (13:00) and 1.052 (12:15) also exhibited considerable anomalies with the 21st, 14th, 10th and 16th greatest monthly surges recorded at Heysham, Hinkley Point, Holyhead and Milford Haven (January and May 1990 to March 2022). Storm surge magnitude during Ciara was anomalously high with six stations (except Newlyn) recording a magnitude in the top 12.1% greatest monthly surges. Precipitation on February 9 also rose starkly with highs of 6 mm and 5.6 mm at Blackpool (08:00) and Usk (12:00). Total rainfall at Blackpool and Usk for February 9 was 124.4% and 93.0% of the 15 day 1991–2020 mean exhibiting the exceptionally high precipitation anomalies.

The Guardian's reporting on February 9 showed the national significance and impact of Storm Ciara as a live feed designated to the storm ran from 15:39 until 23:12 (*The Guardian*, 23:15 9 February). The feed noted the large-scale deployment of emergency services responding to storm and flood impacts. The first national agency response warning came from Scottish Environment Protection Agency (SEPA) which corresponded with the high precipitation recorded in Scotland. SEPA firstly warned of the imminent danger by issuing 63 flood warnings and 15 flood alerts to promote awareness and potentially pre-emptive action. Scotland's transport secretary also emphasised the importance of following national agency warnings and instructions. Dramatic photographs and social media posts from national agencies were also embedded in the feed. The posts further emphasised public warnings, highlighted the danger to life and promoted the Met Office's #WeatherAware (*The Guardian*, 19:04 10 February). The EA South-East likewise urged public caution with the publishing of warning diagrams (Fig. 3) and maps noting the 204 flood warnings and 234 alerts across England. The frequent informative social media posts from governmental agencies reflected an awareness of the high value of social media to communicate important storm information to the public to effectively reduce their vulnerability [34]. The concise posts also highlighted recognition of the need for rapid and clear communication during the event to the large diverse audiences of social media [35]. The embedded feed, therefore, evidences response communication designed to effectively reduce public vulnerability which is vital when increasing climate change threats are considered.

A report on February 10 noted the storm impacts, however, the main focus remained on short-term predictions and widespread warnings (*The Guardian*, 02:36 February 10, 2020). Met Office warnings and the storm threats were emphasised and well-illustrated by a *Guardian* graphic (Fig. 4). The report also featured the first attempt to relate Storm Ciara to long-term governmental response. The shadow environment secretary criticised the government stating that Ciara showed a need for greater long-term government investment to enhance the resilience to increasing high magnitude storms driven by the climate crisis. This statement aligned with the United Kingdom [36] (UKCP18) which predict climate change will likely result in increases in atmospheric storminess, including precipitation, wind strength and storm surge magnitude [2,18]. Regarding long-term UK government policy, there is also a wide consensus that austerity continues to limit climate change adaptation and has increased community storm exposure (e.g. Refs. [37–39].

Subsequent reports on February 10 noted 62 flood warnings in Scotland and 178 in England and Wales. Met Office yellow wind and snow warnings also remained for North-west England and Scotland respectively. The first UKgovernment response was the Bellwin Scheme activation which allowed LAs to apply for extra storm response funds and be reimbursed was noted. The Bellwin Scheme reimburses LAs for expenditure on immediate action to safeguard life, property or prevent suffering and major inconvenience when budgets are exceeded (Sandford, 2015; Gralepois, 2019). Since 1989 the scheme has adapted to improve LA and emergency service response to catastrophes (Raadgever et al., 2018). Key revisions were made following the winter 2013/14 storms which reduced Bellwin thresholds, paid grants at 100% above the threshold and extended spending periods (Bennett and Hartwell-Naguib, 2014). This exhibits UK government short-term catastrophe response adaptability, but frequent policy revision following catastrophe perhaps suggests a partially reactive and short-term strategy as opposed to a proactive long-term approach [37].

The scientific data from February 10 corresponded with the numerous weather warnings. At Blackpool, the wind rose to a site high of 20.1 ms^{-1} (23:00) while a storm surge peak of 1.214 m followed at Heysham at 05:00 February 11 (see Fig. 7). Precipitation on February 10 also conformed with Met Office predictions as the data indicated that precipitation at Stornoway and Bishopton were clear positive anomalies with daily rainfalls of 9.2 mm and 18.2 mm which were 132.5% and 311.7% greater than the February 1991–2020 daily mean. *The Guardian* acknowledged that a range of communities had been impacted by Ciara and asked readers to share their experiences (*The Guardian*, 15:03 February 11, 2020). The further decrease in magnitude was evidenced by the scientific data which showed nearly all variables decreasing until 18:00 to 21:00 on February 12 (except Stornoway precipitation). As magnitude temporarily decreased the reporting focus at 13:04 on February 12 predominantly focused on the impending Storm Dennis. Widespread Met Office and EA weather warnings were reported (*The Guardian*, 13:04 February 12, 2020). While the EA noted rainfall and ground saturation from Ciara would exacerbate Storm Dennis flooding, the Met Office chief meteorologist stated Dennis was 'not expected to be as severe as Ciara'. On the evening of February 12 and on February 13, increases in all variables were noted. Total pre-

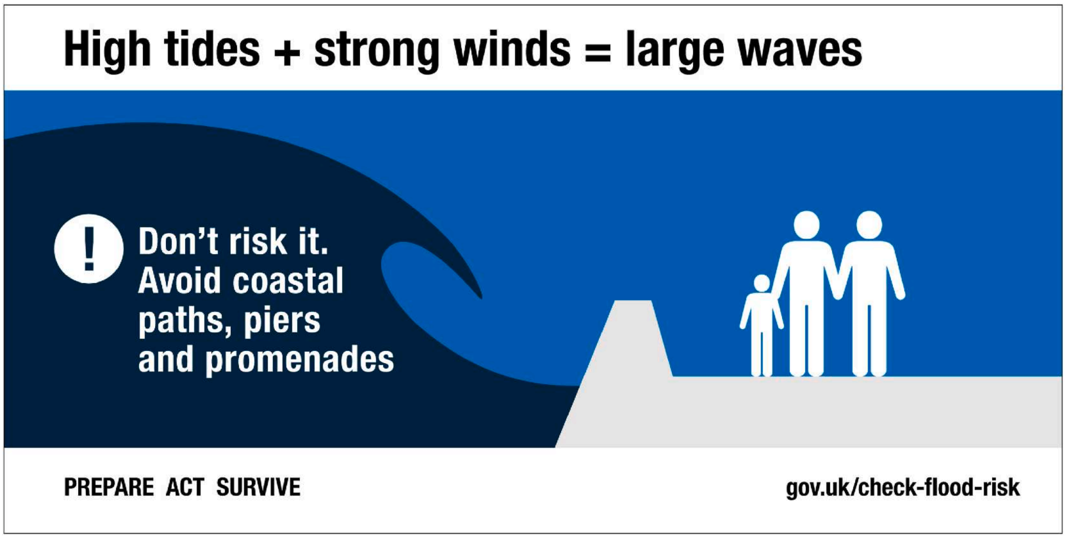

Fig. 3. A wave overtopping warning issued to the general public from the Environment Agency SE featured in *The Guardian's* live feed on February 9.

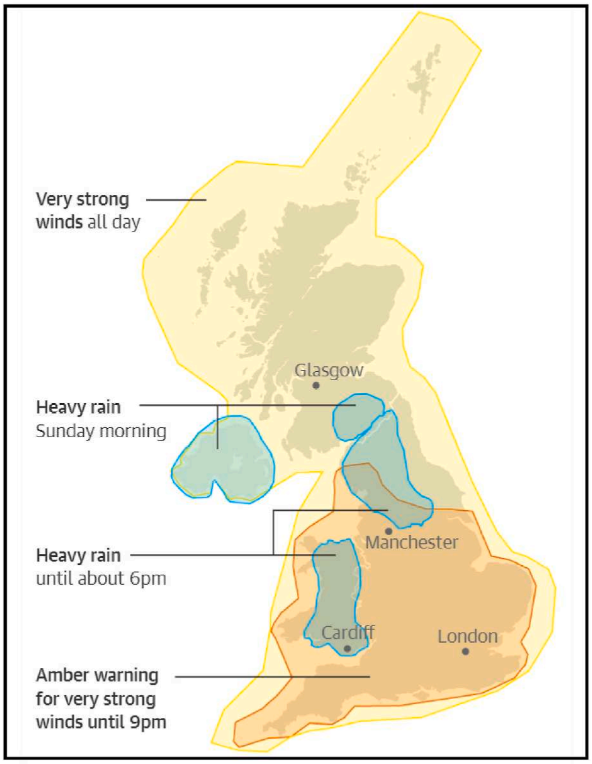

Fig. 4. Annotated storm warning figure created by *The Guardian* using Met Office Data (*The Guardian*, February 10, 2020).

cipitation of 19.4 mm, and 15.2 mm between 14:00 February 12 to 14:00 February 13 were recorded at Usk and Camborne which was 483.2% and 483.7% greater than 1991–2020 24 h means and indicated high storm magnitude in South-west Britain.

Following decreases in all variables in the afternoon of February 13, February 14 was characterised by gradual rises in wind speed and storm surge to maximums of 17.5 ms^{-1} (10:00) and 15.9 ms^{-1} (11:00) at Stornoway and Valley while surge height peaked later at 0.591 m (12:15) and 0.595 m (14:00) at Bishopton and Heysham. No precipitation was recorded until 08:00 at Stornoway (1.6 mm) and rapid increases subsequently occurred with a daily maximum of 4.8 mm (12:00) at Bishopton.

The main reporting emphasis was on the arrival of Storm Dennis and the 'danger to life' Met Office warnings while the EA issued sixteen and 109 flood warnings and alerts respectively (*The Guardian*, 11:50 February 14, 2020). *The Guardian* indicated the wider role of 'climate breakdown' increasing storm severity with extreme rainfall producing 'far higher levels of flooding', although the article (11:50) did not directly attribute the storm period to climate change. This lack of absolute attribution also conforms with the scientific research on the wider 2019/20 storm period which exhibited that, while anthropogenic climate change will likely increase UK storm severity, the stormy winter 2019/20 alone is not proof of such climate change. However, it importantly contributes to the growing evidence that climate change has increased the likelihood of high magnitude storms and extreme rainfall events [7]. Subsequent reporting (17:05) centred on a PwC report, did not mention climate change and instead focussed on the £150–200 m in estimated insurance claims while the climate modeller Risk Management Solutions noted that the storm 'exhibited characteristics typical of European windstorms' (*The Guardian*, 17:05 February 14, 2020). The two articles published at 11:50 and 17:05 exhibit corroboration with wider climate science [27] but the factual reporting indicates objectivity.

4.3. Storm Dennis

The scientific data of February 15 denoted the accuracy of the Storm Dennis predictions as magnitudes rose rapidly. Wind speed increased (see Fig. 7(b)) with an overall storm period maximum of 27.3 ms^{-1} at Mumbles Head (17:00). Storm surge magnitude increased to a site maximum of 1.159 m at Holyhead. Most prominently hourly precipitation reached an overall storm period maximum of 7.8 mm at Usk (15:00) while Bishopton received 5.8 mm (16:00). *The Guardian's* initial reporting reflected the observed increases in magnitude with a focus on visual storm representations throughout Western Britain (Fig. 5) (*The Guardian*, 15:15 February 15, 2020). Likewise, an 18:58 report highlighted the dramatic storm effects predominately using photography (*The Guardian*, 18:58 February 15, 2020). While the first reports may have been media heavy because written reports were in progress, *The Guardian* may have adopted this approach as imagery and videos effectively attract initial attention and awareness while stimulating public engagement [40,41].

At 07:22 on February 16 a predominately written report on Storm Dennis focussed on the numerous public risks indicated by 472 EA flood warnings (103) and alerts (369) in England and Wales along with eight Met Office warnings (*The Guardian*, 07:22 February 16, 2020). The subsequent live blog (09:02 to 20:05) featured a combination of impact reporting, warnings and response from

Fig. 5. Storm surge conditions and public observers in Porthcawl, Wales on February 15 featured in *The Guardian*.

governmental agencies as well as the national political response (*The Guardian*, 20:05 February 16, 2020). The feed highlighted the widespread action of the government agencies concerned with short-term storm response and relief as UK warnings and alerts reached a record 594 by 12:48. Likewise, the 'major response' of South Wales police and the Met Office issuing of a red warning for South Wales was emphasised. Much of the impact reporting was focused on South Wales where hundreds had been affected by flooding in the Rhondda Valley and the police reported a death in the River Tawe (*The Guardian*, 20:05 February 16, 2020). The feed also featured accompanying tweets from relevant organisations which clearly outlined public risks and ways to reduce vulnerability. This again signified recognition of the importance of clarity and the use of social media for rapid and effective public risk communication [42].

Additionally the feed featured tweets from the Pontypridd MP, Alex Davies-Jones MP, who initially posted regarding her liaison with the Rhondda Town Council and Welsh Government over how to best help those affected by 'truly heart breaking' flooding (*The Guardian*, 20:05 February 16, 2020). This was followed (11:09) by an announcement of her crowdfunding scheme before (15:46) an announcement of the evacuation of 600 people. Davies-Jones however exclaimed that the response from communities and local government agencies had been 'brilliant'. Fellow Labour (opposition) Rhondda MP, Chris Bryant, also set up a relief fund for the hardest hit and poorest without flood insurance (*The Guardian*, 20:05 February 16, 2020). This was the first localised short-term response from Westminster MPs whose actions signified that even effective regional short-term response could not prevent an emergency. The government insisted its preparedness and response were sufficient and did not declare a national emergency but acknowledged the local emergency in South Wales. Instead, the environment secretary stated full mitigation was impossible due to the 'nature of climate change'.

The scientific data exhibited the extreme weather anomalies in South Wales. Maximum hourly precipitation at Usk totalled 6.8 mm at 04:00 and 94 mm of rain fell throughout February 15 and 16. This was 1320.1% greater than the 1991–2020 mean February two day total (6.6 mm) and conferred with the long-term climate change trend predictions regarding increasing storm precipitation [43]. Storm surge magnitude at Hinkley Point increased to 1.133 m at 01:15 and at Heysham and Blackpool the surge morning peak was 1.204 m at 09:15 while wind speed peaked at 04:00 at 16.5 ms^{-1}. After 12:00 February 16 wind speed and storm surge magnitude increased at most sites as wind speed rose to 22.6 ms^{-1} at Mumbles Head (22:00) and surge reached a maximum of 1.314 m at Heysham (22:30). This period of prolonged high storm magnitude further conforms with UKCP18 predicted trends of climate change-catalysed increases in magnitude in Western Britain [7,18].

4.4. Aftermath, response and long-term effects

February 17 was largely defined by decreases in wind speed and storm surge height across all sites (Fig. 7). At most sites precipitation decreased from February 15 and 16, except at Bishopton (max 7.4 mm at 05:00). At Usk, an hourly max of 2.2 mm (05:00) was also recorded, and rainfall did not exceed 0.8 mm except at Bishopton after 10:00.

The Guardian's focus likewise showed the decreasing short-term impacts. A 07:40 article on February 17 focussed on the wider £1.2 bn Met Office forecasting supercomputer project, noting how this innovation could improve forecasting and preparedness (*The Guardian*, 07:40 February 17, 2020). At 13:25 the focus shifted to addressing key questions concerning Storm Ciara and Dennis and their impacts. *The Guardian* emphasised that the exceptionally high magnitude of storms had increased vulnerability while stressing that physical defences were only part of the armoury (*The Guardian*, 13:25 February 17, 2020). However, the EA's long-term defence plans were shown to have great importance as 150,000 homes had been protected between 2015–18 and 499 more projects would protect 341,875 homes between 2019–21 (see Fig. 6). While the government stated it invested in 'areas of the highest priority' *The Guardian* noted critics believed that there was a bias towards urban areas and areas of economic high value. *The Guardian's* critique cited flood expert Professor Hannah Cloke (University of Reading) who stressed the need for increased 'natural flood management' although Professor Robert Wilby (University of Loughborough) noted more than natural measures would be required to mitigate storms like Ciara and Dennis. Uncited experts also demanded more contingency plan-

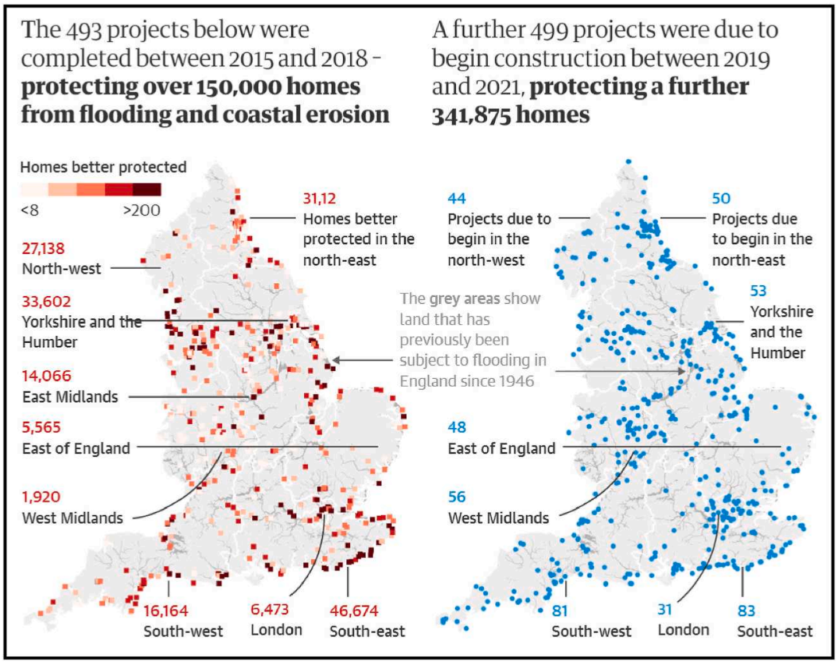

Fig. 6. Environment Agency flooding defence and management projects in England between 2015-2018 and 2019–2021 in *The Guardian* on February 17. *Guardian* graphic created with EA information.

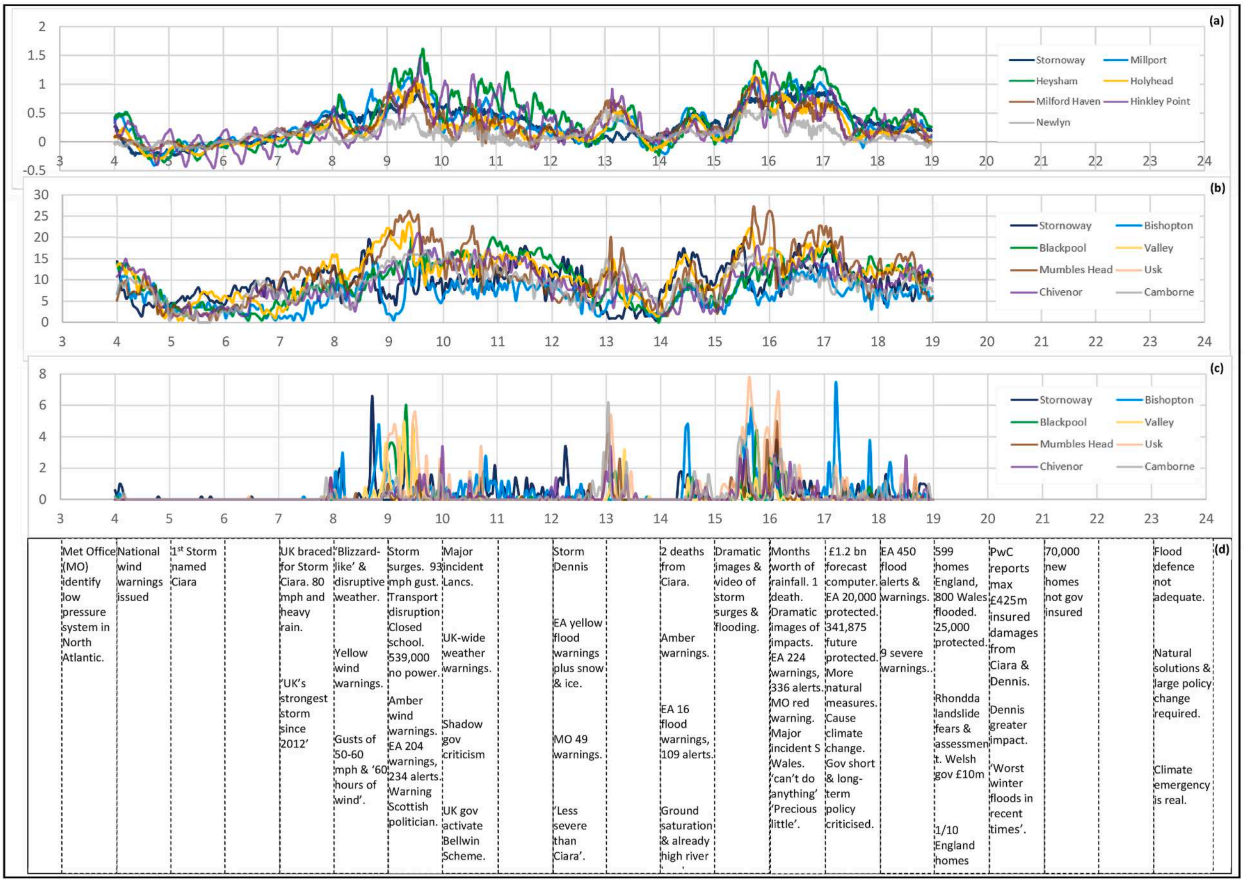

Fig. 7. Timeline of variability in storm surge magnitude in m (a), wind speed in ms^{-1} (b), precipitation in mm (c) as well as the corresponding key reported storm impacts and government response (d). The x-axis of graphs represents time (date).

ning, local resilience measures and defence management. Balance to this technocracy and nature-based argument was also provided as it was stated the Met Office's supercomputer would improve storm forecasting. Short-sighted funding and restrictions were noted as limitations preventing required adaptation. Ground saturation resulting from exceptional rainfall was stated as the immediate flood cause, while *The Guardian* stated that the 'climate emergency' was the long-term cause and referred to Met Office evidence noting the increasing number of UK storms.

The 13:25 report complies with relevant research concerning the short-term storm characteristics and effects. The anomalously high Autumn 2019 rainfall majorly contributed to the flooding, as the subsequent heavy rain during the storm period fell on highly saturated ground and therefore rapidly entered rivers and overwhelmed defences [7,44]. While a broad agreement exists regarding the influence of long-term climatic change on increasing UK storm severity and precipitation [18], most research avoids direct attribution. [7]; p.396) note that climate variability likely produced Storms Ciara and Dennis while stating anthropogenic climate change increases the likelihood of 'extreme rainfall like that in February 2020' [44]. emphasise the correspondence of the Winter 2019/20 precipitation with climate change predictions, but avoid direct attribution, noting that although most studies partially attribute major storms to climate change, differentiating extreme events from natural variability remains complex. However, all the research suggests that Storms Dennis and Ciara conform with the observed and predicted climate trends of increasing storm magnitude.

The subsequent article in *The Guardian* opinion column echoed the predominant climate consensus and adopted a highly critical stance. The article 'Flooding in the UK isn't an act of God, it's an act of government' mostly conformed with scientific expertise in an attack on governmental climate change and flooding adaptation policies (*The Guardian*, 13:56 17 February). The author, aligned with the science stating 'whatever may be the role of the climate emergency' before exclaiming the widespread storm catastrophe showed major policy change was required (*The Guardian*, 13:56 February 17, 2020). The need for more natural flood management over technocracy was stressed. This opinion is supported by Ref. [45] who recommend introducing more nature-based flood measures as they found during Storms Ciara and Dennis that hedgerows were highly effective at reducing overland flow in Cumbria [46]. study of Ciara and Dennis also evidences that well-designed nature-based solutions could complement traditional strategies and reducing exposure and defence requirements. Norbury et al.*'s* [47] study of Ciara and Dennis in the Pennines likewise showed that willowed engineered log jams can reduce peak discharge by 27.3%, thereby reducing flood risk, however most research also conforms with Professor Wilby reported stance that natural measures must also be supported by traditional defence methods (*The Guardian*, 13:25 February 17, 2020).

Despite the greater long-term focus, at 15:38 (*The Guardian,* 17 February) reports highlighted that Dennis still posed threats with 250 UK-wide EA flood warnings in place, while the plight of flooded communities in South Wales and national travel disruption continued. At 16:23 a more balanced article drawing on information from governmental agencies and climate experts discussed the long-term climate and flooding policy. *The Guardian* reemphasised the environment secretary's affirmations that 'the nature of climate change' prevented complete protection and the government 'had done everything with a significant sum of money' and more money was forthcoming (*The Guardian,* 16:23 17 February). The article favoured more natural drainage systems to mitigate the 'crisis'. After noting the future rainfall and runoff uncertainties predicted by the James Hutton Institute, *The Guardian* further supported the science-based case for increased nature-based solutions. An expert in UK coastal defence stated that the UK's coastal defences were insufficient when future climate change was considered and called for more 'non-structural solutions' using 'holistic and integrated' frameworks (*The Guardian,* 16:23 17 February). Climate Coalition scientists also highlighted that a major flood had occurred annually since 2007 and expressed the role of anthropogenic climate change in increasing rainfall magnitude. The article, however, concluded by referring to objective scientific predictions as only some Met Office models suggested climate change would increase future storminess but extreme rainfall events will become more frequent.

The subsequent opinion article (*The Guardian*, 18:56 17 February) adopted a more critical stance with a predominant focus on long-term government climate policy. While the Prime Minister's absence in areas flooded was criticised, the article focused on the contradiction of the government claiming it had done everything to prevent flooding and its failure to meet 2025–2030 emission targets. The article then emphasised how likely evidence of climate change required climate and energy policy change. Past conservative governments were also condemned for 'reckless' funding cuts and planning law and 'intelligent land and river management' were identified as requiring major change to decrease climate change vulnerability (*The Guardian*, 18:56 17 February).

This narrative is echoed in wider research as [48] also exhibit that the current economic and industrial structure of the UK produces significant government challenges if climate and environmental goals are to be addressed while also meeting other public objectives. At a regional level co-benefits of climate action are better incorporated into the decision-making process in the short-term while at the national level greater collaboration between departments means the co-benefits of climate action are more likely considered. Increased power devolution also enhances long-term climate resilience allowing LA to adopt longer-term policy approaches with benefits ranging from improving energy security to lowering NHS extreme weather admissions.

In response to the wide demand for strategic change, the UK government produced the first Net Zero Strategy in 2021 which seeks to reach net zero carbon emissions and end the UK's domestic contribution to man-made climate change by 2050 (UK Government, 2021). The £26bn Ten Point Plan aims to radically change energy supply, transport, infrastructure and employment to achieve this. While the changes are significant and suitably ambitious, independent groups (i.e. Climate Change Committee (CCC)) have identified key issues regarding plan detail and delivery in key sectors. The CCC has also criticised the lack of a net zero test to ensure policy suitability and alignment with consumer demand (CCC, 2021) with subsequent legal challenges being upheld in the UK high court (*The* [49,50]. Therefore, while there is evidence of significant governmental attempts to address the climate crisis and respond to the issues highlighted in the reports and wider research, major challenges remain.

The final impact-focused storm report remained highly critical, blending reporting of the storm impacts as well as the short-term response and long-term issues related to climate change adaptation and policy (*The Guardian*, 20:38 17 February). While the UK and

Welsh governments reiterated the success of flood defences and their response, the Welsh First Minister noted that short and long-term policy change relating to flood management and wider climate change was required.

Magnitude decreases of all three variables on February 18 evidenced by the scientific data marked the end of Storm Dennis (Fig. 7). However, the widespread saturation reflected the continuing EA warnings in the 08:47 article which noted 450 alerts and warnings remained with South Wales under particular threat (*The Guardian*, 08:47 18 February).

The decreasing storm magnitude was shown by reporting which adopted a more reflective tone. The main impacts were in the Rhondda Valley where 600 people were evacuated and 1000 homes affected. Although EA and Met Office warnings persisted the focus increasingly turned to the large socio-economic losses, especially in South Wales. Rhondda Cynon Taf council released a reserve £1 m and £10 m more was promised for Welsh councils although the council leader estimated a bill of 'millions and millions of pounds' (*The Guardian*, 16:24 19 February). Water supply issues in Monmouthshire and travel to key sporting fixtures in Wales were impacted resulting in further losses which resonate with the increasing socio-economic impacts resulting from more frequent high magnitude storms caused by climate change [51]. Since the floods of summer 2007 an estimated 88,683 UK properties have been flooded during five 'record-breaking' storm periods, consistent with climate change projections [51]. During the winter storms of 2013/14 alone, the UK government estimated England and Wales alone sustained economic losses of £1.3bn [52]. Reports likewise initially noted the high economic cost of Storm Dennis as PwC reportedly estimated a national insured loss of £175-£225 m (*The Guardian*, 14:13 20 February), which brought the highest PwC estimate for insured losses from Ciara and Dennis to £425 m. Insured storm losses however likely represented a fraction of the overall loss as uninsured losses as well as losses to commerce are usually far greater [53–55]. The estimates highlight the large socio-economic costs sustained during or immediately after storms and floods and such losses will likely increase with climate change.

By 18:24 on February 19 reporting concentrated on long-term planning and climate change adaptation policy and governance shortcomings. Emphasis was placed on 'official figures' of the 84,000 new homes built in areas at the highest risk of flooding which represented 1 in 10 of all new builds since 2013 (*The Guardian*, 18:24 19 February). While *The Guardian*'s analysis importantly ignored the presence of all existing flood defences, the concerns regarding development in high risk areas were echoed by flood expert Professor Wilby who noted how construction on floodplains compounded risk. A lead councillor's concerns regarding LA' predicament between satisfying government housing quotas and flood risk were also highlighted. Reports noted that the Government's stated high risk development could only occur when absolutely necessary and after all resilience measures had been taken. The storm period vulnerability was stated to be in part due to funding limitations with *The Guardian* and Professor Cloke noting that more funding, particularly for nature-based solutions, would aid preparedness and decrease risk. The critique of government housing policies continued on February 21 as *The Guardian* reported the Bright Blue thinktank had identified that 70,000 new homes built after January 1, 2009 did not qualify for the government Flood Re insurance scheme. Placing a personal responsibility on homeowners to assess flood risk was branded 'heartless' although a government investigation was instigated (*The Guardian*, 00:01 21 February).

The critique in two articles on February 23 reinforced the issues of inadequate government planning policies and long-term climate change adaptation (*The Guardian*, 12:28 23 February; *The Observer*, 06:12 23 February). The *Observer* focused on expert concerns regarding the inadequacy of current UK flood and storm management. Professor Cloke advocated a 'complete overhaul' of defences while Dr Heidarzadeh (Brunel University), a coastal flood expert, noted decades-old defences could not 'address the current climate situation' due to increasing major storms and floods ([8] *The Observer*, 06:12 23 February). The environment secretary's proposition to introduce more nature-based solutions was criticised as Professor Falconer (University of Cardiff), noted such measures would 'certainly be insufficient when addressing the 30% increase in winter rainfall' predicted by the Met Office in certain areas. Expert Professor Sear (University of Southampton) also noted the political implications of addressing flooding, stating that politicians must understand 'the facts of flooding' before policy adoption.

A review of related policy however does highlight that the government has exhibited a degree of climate change adaptation. The EA has extensive information and guidance for authorities seeking funding to adapt to climate change-driven increases in flood and coastal erosion risk[56]. The policy dictates that funding allocation is based on site-specific assessments using science-guided 'climate change allowances' that concern anticipated changes for: peak river flow, peak rainfall intensity, sea level rise as well as offshore wind speed and extreme wave height. The EA states that this ensures that funding is allocated to areas where 'it provides the biggest benefit' although exceptions to the use of climate change allowances may be granted (HM Government, 2022). While [57] scientific review of river flood risk management in England highlights government agencies has increasingly incorporated climate science into policy, more emphasis and resources must be devoted to improving the integration between policy, strategic planning and local delivery to prompt effective climate change responses. Researcg notes an enhanced impetus on stakeholder engagement and community participation in science-guided schemes is also key to ensuring their long-term effectiveness [58,59]. [38] further conform with *The Guardian* narrative noting that UK government austerity reduces community engagement and ultimately increases storm and flood vulnerability.

The final article published on 23 February at 12:28 similarly highlighted inadequate government policies but placed a greater focus on planning policies. An analysis by *The Guardian* and Greenpeace which ignored current flood defences concluded 11,410 new homes were planned in areas with the highest flooding risk. The chief scientist at Greenpeace UK noted this underlined the major shortcomings of the planning policies which would exacerbate the impacts of more frequent climate change-driven future flooding. Council members in affected areas likewise condemned the plans while the government policy to avoid high risk development was reiterated. The Greenpeace UK chief scientist implied that the government was insincere about climate change and prioritised home builders profits over future flood protection, as LA and EA budget cuts favoured developers. This concluded *The Guardian's* coverage of the storm period which importantly sought to raise public awareness of the influence of climate change on extreme weather. Notably the reporting represented the impacts of the storm period not as an independent unpreventable disaster but as an inherent climate catastrophe influenced by societal and political action. This form of representation is globally very important if the public are to become aware of and ultimately engage in enhancing climate change resilience which has a major effect on community vulnerability.

Regarding planning and housing policies which plausibly have the greatest direct impact on communities, the wider research regarding climate change adaptation in the UK broadly agrees with *The Guardian's* consensus. In coastal urban regions planning system adaptation is focused on experienced hazards and is incremental rather than transformative, while climate change adaptation is seriously limited by government emphasis on housing and economic growth as well as the developer's economic focus [60]. This reactive policy adjustment was evident in the February 2020 storm reports. Only after the event were extensive flood investigations permitted and undertaken at a local level to 'truly learn the lessons' and ultimately improve infrastructure and planning [61,62]. Further [63], note coastal risk management must adapt to integrate planning, engineering and insurance approaches to be effective against climate change. Limited climate change risk planning also places a disproportionate number of poorer, vulnerable neighbourhoods at risk, serving to increase the impact [64].

Explaining why the UK government has, according to the majority of relevant research, failed to implement suitable climate change-related policies is complex. Peer-reviewed research often cites austerity as a major contributing factor whether directly resulting from the 2010 budget issued by the ruling conservative party or as a continuing legacy of reluctance to properly invest in climate adaptation. Den Uyl and Russel [65] state how a lack of clarity around responsibility for addressing climate impacts and a lack of a deliberative structure between various governmental, private and community stakeholders, within a context of austerity, hamper climate change adaptation which has resulted in high storm vulnerability on the South Devon coast [39]. also notes that despite being the first country in the world to set statutory carbon emissions reduction targets (in the Climate Change Act 2008 implemented by the Labour government), the subsequent Conservative government has fallen increasingly behind the government's own regulation standard since 2012 [39]. notes how a range of policies ranging from EA budget cuts, a reliance on market forces over regulation and a high degree of continued dependency on fossil fuel-based energy policies have contributed to a climate catastrophe in the UK. These policies have ironically resulted in a situation where radical solutions are now even more necessary and more urgent. The allegations made by Greenpeace's UKchief scientist are also supported in relevant research that notes that while Local Enterprise Partnerships (LEPs) provide space for some co-ordination, LEPs have had their funding cut and are dominated by business and developer interests which means that climate targets are often a secondary consensus. Local authorities have also noted that changes to the National Planning Policy Framework, based on a view that excessive red tape was holding back housebuilding and economic growth, had made it much harder to achieve climate change goals through local planning decisions [66]. This government planning relaxation and emphasis on economic growth therefore limits climate change adaptation and ultimately increases long-term community and ecosystem vulnerability [67,68].

Positively, the UK government doubled its investment in flood and coastal management in England in 2020 and the Environment Agency also revised the programme of flood and coastal erosion risk management (FCERM) to allow devolved partnerships comprised of individuals with diverse expertise to better address fluvial and coastal climate threats [69]. In the same year the government also introduced three innovative programmes to improve resilience to flooding and coastal change throughout England while Scotland, Wales and Northern Ireland have similar schemes [70]. Although the schemes increasingly seek to facilitate sustainable long-term climate hazard resilience, schemes only commit funding until 2026 (Scotland) and 2027 which can limit the scope and commitment of mitigation strategies, while the scale of investment that is required may render the budget inadequate particularly when community support is considered [71,72]. There are also considerable challenges to be overcome concerning forming effective multidisciplinary coastal partnerships, producing and accessing accurate data to inform policies, as well as changing public and political attitudes regarding the adoption of new sustainable coastal management practices which can contradict entrenched long-term policies [73–75]. In all, this original mixed methods analysis blending quantitative weather and qualitative newspaper data with wider research exhibits that there must be an increased government impetus to better facilitate long-term climate change adaptation [64,76].

5. Conclusions

The combined data highlight that Storms Ciara and Dennis represent a high magnitude storm period that had large socio-economic impacts throughout Western Britain and the UK. The impacts merited major immediate community, LA and government responses as well as bringing a range of long-term government policies into question.

The scientific data exhibit the very high storm magnitude and statistical climate anomaly. Mean wind speed across the seven sites was on average 3.1 ms^{-1} or 48.8% greater than the combined 1991–2020 February mean. Storm surge magnitude was also anomalously high as a top 30 monthly surge (January/May 1990 and March 2022) was recorded at all stations. Precipitation also exhibited very high positive anomalies as at all eight sites the storm period total precipitation was on average 58.5 mm or 122.2% higher than the 15 day February 1991–2020 mean. At Usk, the precipitation anomaly was greatest being 140.7 mm (282.3%) higher than the February mean. *The Guardian* reports conferred with the scientific data and evidenced the widespread storm impacts in Western Britain.

While wind strength and tidal surges values were substantially greater than the February means, precipitation, was the greatest anomaly. This conforms with UKCP18 climate change predictions of likely increases in twenty-first century storminess in Western Britain [2,18] as well as Met Office predictions of climate change increasing winter rainfall by 30% by 2070 in certain regions [43].

The Guardian storm reports record considerable evidence of proactive storm warnings, efficient public hazard communication as well as effective storm and flood response by LAs, emergency services and communities. This short-term response was praised in *The Guardian* reports as well as in objective reviews undertaken by national and local governments (Griffiths, 2020; *The* [77–104]. The newspaper reports themselves also exhibited a conscious effort to enhance public awareness through clear and well communicated public warnings with the aim of reducing public vulnerability. The reports, however, indicated that the high storm magnitude overwhelmed mitigation and prevention efforts in certain areas and ultimately produced the catastrophe (e.g. Refs. [62,104]. This consensus puts the long-term government adaptation policies into question, especially when the correspondence between the storm period magnitude and known UK climate predictions is considered (Lowe et al., 2018; [7,9].

The Guardian articles frequently criticised the shortcomings in the UK government's long-term fluvial and coastal management policies as well as the wider government approach to climate change adaptation. Most independent peer-reviewed research corresponds with *The Guardian* narratives and likewise suggests multiple long-term government policies require extensive revision and, in some sectors, complete change to enhance UK climate change resilience (e.g. Refs. [60,76]. As climate change will likely increase high magnitude storm frequency and winter rainfall magnitude, *The Guardian* and the peer-reviewed research share the consensus that events similar to Storm Dennis and Ciara will become increasingly prevalent in Western Britain [18,105]. While communities, local authorities and government agencies will do everything possible to mitigate and effectively respond to storm threats, more major long-term government policy change is required across multiple sectors to adequately address fluvial and coastal threats enhanced by climate change [36,76]. Likewise, it is also important that media agencies continue to clearly communicate climate threats to enhance public preparedness and awareness if resilience is to increase. In addition, it is crucial that the media continues to publicly highlight hazard events not just as independent unpreventable disasters but as a part of the climate crisis which is ultimately something that can only be tackled with wider societal and political action throughout the World.

Although the government has made significant attempts to address the climate crisis [106], a range of fluvial and coastal management policies as well as the wider approach to climate change adaptation remains insufficient [38,57,63]. This study ultimately shows that original mixed methods research combining quantitative weather data, qualitative newspaper reports and wider peer-reviewed research can highlight the need for further policy adaptation aimed at reducing climate change and extreme weather impacts. This will increase the ability of stakeholders to mitigate and prevent climate catastrophe, and ultimately enhance community climate change resilience.

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.

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