Climate Risk Management 37 (2022) 100440

Contents lists available at ScienceDirect

Climate Risk Management

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

UK Climate Risk Assessment and Management

The concept of climate risk has become increasingly important and central to climate change research (Reisinger et al., 2020) and practice (Willows and Connell, 2003) over the last two decades. Climate risks result from the interactions of climate-related hazards with the vulnerability and exposure of human and natural systems, as well as human responses to climate change (such as adaptation).

Mandated by the 2008 Climate Change Act, the UK Government is required to publish a climate change risk assessment (CCRA) every five years, with the third CCRA being the most recent (HM Government, 2022). Since the publication of the second risk assessment in 2017, significant scientific advancements have occurred. This has been accompanied by the emergence of a UK community of researchers and practitioners working on climate science, impacts, adaptation, vulnerability and services who use climate risk as a central concept.

This Special Issue is the result of *Climate Risk Management*'s first Open Special issue (launched in 2020), which sought contributions of new and original research on UK climate risk assessment and management in order to support the evidence base for the UK's Third CCRA. The Special Issue includes twelve papers that span both the assessment and the management of climate risk in the UK. Several papers focus on water-associated risks, with analysis ranging from the national to the catchment scale. These papers include scientific and methodological innovations in the assessments of flooding in Great Britain (Kay et al., 2021), drought in Scotland (Visser-Quinn et al., 2021), river water temperatures in England (Wilby and Johnson, 2020), river ecosystem resilience in the Lee catchment (Murgatroyd and Hall, 2021) and the assessment of two potential adaptation strategies, namely inter-basin transfer schemes to address the risk of drought in England (Khadem et al., 2021) and domestic raintanks to increase urban flood resilience in Hull (Sefton et al., 2022). Two papers focus on national assessments of climate hazards and risk, with Arnell et al. (2021) developing hazard indicators for multiple sectors and Garry et al. (2021) assessing the risk of compound events on UK agriculture. Additionally, two papers extend their analysis to include economics, by estimating the damage costs of erosion hazards on critical infrastructure in Cockermouth (Li et al., 2021) and by conducting a cost-benefit analysis of adaptation to heat under a changing climate in a care home context (Ibbetson et al., 2021). The final two papers use social science methods to explore farming stakeholders' experiences and their responses to extreme weather and climate change (Wheeler and Lobley, 2021) and to compare different climate risk management frameworks and their implementation (Smith et al., 2022).

Flooding poses a risk to people, infrastructure, and ecosystems. In their paper, Kay et al. (2021) develop a nationally-consistent assessment of the sensitivity and vulnerability of flood peaks across Great Britain to climate change. The sensitivity-based approach is applied to a national-scale, grid-based hydrological model (Grid-to-Grid; G2G), outputting modelled flood response surfaces for every river cell on a 1 km grid. These flood response surfaces are then combined with the probabilistic UK Climate Projections 2018 (UKCP18) to provide location-specific information on the potential range of impacts on floods across the country for three flood return periods, three future time-slices and four emissions scenarios. Flood peak changes for 1 km river cells show significant spatial variation, with impacts typically higher in the west than the east. The study has produced a wealth of data that can be explored by users through a web-tool (https://eip.ceh.ac.uk/hydrology/cc-impacts/).

Scotland is a water-rich nation with an ambition to become a "hydro nation": a nation in which water resources are developed to bring maximum benefit to the country. But Scotland is increasingly vulnerable to periods of dry weather, putting pressure on water users and the environment. In their paper, Visser-Quinn et al. (2021) assess the impact of climate change on drought prevalence and how abstractions by the water sector may exacerbate this pressure in Scotland in the near future (2020–2049). Their objective was to identify existing and emerging drought hotspots and to explore climate model uncertainty through a multi-model ensemble and a perturbed parameter ensemble. They find two hotspot areas in both ensembles: the rivers Spey and Tay, centres of the Scottish whisky and agricultural sectors respectively. The results indicate that abstraction will exacerbate the pressure on water resources from climate

https://doi.org/10.1016/j.crm.2022.100440

Available online 26 May 2022

change and that the perturbed parameter ensemble had narrower uncertainty bounds than the multi-model ensemble. The authors conclude that a consistent approach to future water resource planning across Scotland is needed.

Water temperature is a primary determinant of freshwater ecosystem health and function. In their paper, Wilby and Johnson (2020) analyse a unique national archive of nearly one million water temperature values in England to assess recent changes in variability, correlation with the North Atlantic Oscillation (NAO) and differences between open, shaded and spring-fed river reaches. They find that the strength of the correlation between water temperatures and NAO varies in space and time across England, which matters for schemes intended to keep rivers cool because natural climate variability already makes trends based on field data difficult to assess and interpret. They argue that quality assured records for a few rivers where the likelihood of trend detection is high should be the basis for a priority national indicator of long-term water temperature for UK CCRAs. Their catchment-scale analysis shows that the assessed thermal benefit of riparian shade depends on physical location within the river network and on prevailing climate conditions, which has practical implications for the design of adaptation measures intended to 'keep rivers cool'.

Also focused on river health, Murgatroyd and Hall (2021) develop a new framework to assess the impact of regulatory policies on river ecosystems under a changing climate. They use a combination of empirical evidence of ecosystem condition with simulation to propose and test adaptations to regulatory limits on river water withdrawals and downstream minimum flow requirements. The study uses multi-level linear models to quantify macroinvertebrate response to future flow scenarios (using very large samples of weather sequences from the Weather@home project) and demand forecasts in the Lee catchment (England). Their results indicate that macroinvertebrate health will worsen under future climate conditions, and that the existing regulation policy must be modified. Their work points towards more outcome-based management of ecosystem resilience.

One potential solution to the risk of droughts are inter-basin transfer (IBT) schemes that move water from where it is abundant to where it is scarce. Khadem et al. (2021) examine the feasibility of IBT of water to manage climate risk in England. They develop a framework that evaluates the negative hydrological and ecological impacts of IBTs to the exporting basin and test it in a hypothetical IBT scheme, delivering water from the northeast of England to London. Three IBT scenarios are considered against the driest UKCP18 local projections. Their results show the projected water deficit in London could be satisfied by an ambitious North-South IBT without negatively impacting the exporting basin, even under the driest projected climate scenario. Although the hydrological risk is sensitive to the IBT operation, it can be minimised if larger volumes are only transferred in winter months.

Another potential solution to droughts and floods is rainwater harvesting. In their paper, Sefton et al. (2022) investigate the technical and social feasibility of developing a domestic raintank programme to increase urban flood resilience in Hull. This interdisciplinary study addresses both technical and social questions together. Hydrological modelling of different types of tanks are used to determine the advantages and disadvantages of different models in controlling runoff. Qualitative socio-cultural interviews with local people reveals that raintanks are broadly acceptable to the local community. Using an action research methodology, Sefton et al. (2022) show that there are transformative advantages to a more community-oriented approach to flood resilience, particularly the potential to change the relationship between the public and flood authorities away from a traditional model that pictures the former as passive, towards a process of mutual learning and two-way communication.

Climate hazard information can support risk management and adaptation planning. In their paper, Arnell et al. (2021) develop a consistent series of policy-relevant indicators of changing climate hazards and resources for the UK covering multiple sectors and using the UKCP18 projections. They find that climate risks will increase across the whole of the UK – in the absence of adaptation – but at different rates and from different starting values in different regions. The number and likelihood of heat extremes affecting health, the road and rail network, and crop productivity will increase very markedly. Agricultural and hydrological drought risks increase across the UK, as does wildfire danger. Fluvial flood hazard increases, particularly in the north and west. These results, which are available on a website (https://uk-cri.org/), provide evidence to support the development of national and local climate resilience policies.

Compound climate events include combinations of multiple climate drivers and/or hazards that contribute to societal or environmental risk. In their paper, Garry et al. (2021) assess current and future risk of compound events impacting UK agriculture. They use the UKCP18 projections to explore how the frequency and duration of instances of potato blight and thermal heat stress to dairy cattle may change. They combine hazard (temperature and humidity data) with vulnerability (specific threshold exceedance) and exposure (regional dairy cattle numbers/potato growing area) to estimate risk. They find that by 2070, potato blight occurrences may increase by 70% in East Scotland and between 20% and 30% across the East of England, the Midlands and Yorkshire and the Humber. The number of days where heat stress to livestock is experienced may increase by a factor of four across large parts of England and by a factor of 10 in South-West England.

Estimating the economic damages from climate change can help inform adaptation investment decisions. In their paper, Li et al. (2021) develop a novel modelling framework to assess the economic impact of erosion hazards on critical infrastructure and evaluate their vulnerability and resilience to a changing climate. They apply the framework in Cockermouth (in NW England) using a hydro-sedimentary model to simulate fluvial and hillslope sediment erosion and deposition caused by extreme storms within river catchments and the UKCP18 Local projections. They find that the magnitude of the hazard may increase under a changing climate. The highest costs are likely to be associated with damage caused to bridges (£102–130 million), followed by sediment deposition in the urban fabric, and erosion damage to agricultural land, buildings and roads. Their Estimated Annual Damage costs suggest that investment in bridges (£4–6 million) in the Cockermouth area is required now to ensure their resilience to extreme storm events.

Cost-benefit analysis can also help decision-makers assess the value of different adaptation strategies. In their paper, Ibbetson et al. (2021) explore methodological issues core to the health cost-benefit assessment of adaptation to heat under a changing climate, among the residents of care homes. They use building physics modelling to quantify the impact of external window shading on indoor temperatures and explore different assumptions about loss of life expectancy. External window shading is estimated to reduce mean indoor temperatures by 0.9°C in a 'warm' summer and 0.6°C in an 'average' summer. The authors show that modest cost adaptations to heat risk may be justified in conventional cost-benefit terms, even under conservative assumptions about life expectancy. These results should encourage further consideration of physical heat adaptation measures in care homes.

Extreme weather and climate change impacts on agricultural production. In their paper, Wheeler and Lobley (2021) conduct qualitative research, based on 31 in-depth interviews, exploring farmers' and other agricultural stakeholders' experiences, attitudes and responses to extreme weather and climate change in the UK. The results suggest a mixed picture of resilience to climate risks within the UK farming industry, with all interviewees having experienced or witnessed negative impacts from extreme weather events in recent years. Despite this, they find that many in the industry are concerned that too few farm businesses are not taking sufficient action to increase their business resilience to extreme weather and climate change. Many of the interviewed farmers did not perceive adaptation as a priority and viewed the risks as either too uncertain and/or too long-term when many are preoccupied with short-term profitability and business survival. Their findings reveal several actions that can help enable adaptation at the farm level.

The International Standards Organisations (ISO) published guidelines for assessing the risks related to the potential impacts of climate change in February 2021 (known as ISO 14091). This standard provides a basis for climate change adaptation planning, implementation, and monitoring and evaluation for any organisation, regardless of size, type and nature. In the final paper of this Special Issue, Smith et al. (2022) compare ISO 14091 with the UK Climate Impacts Programme (UKCIP) climate risk management framework and its implementation. Overall, they find broad consistency – e.g., similar concepts of risk are employed – but there are also important differences. One such difference is that UKCIP and some of its implementation engages more seriously with deep uncertainties, multi-criteria analysis, and co-benefits, while ISO 14091 addresses systemic risk and equity more extensively. The authors provide suggestions on improving the frameworks and guidance for climate risk practitioners.

The collection of papers demonstrates significant advancement in the assessment of climate risk across the UK and across sectors, including water, agriculture, human health, and infrastructure. The papers also show an enhanced understanding of the management of climate risk in the agriculture sector and novel assessments of adaptation strategies in the water and health sectors.

Acknowledgements

Suraje Dessai acknowledges support from the SPF UK Climate Resilience Programme (NE/S017321/1). Kate Lonsdale and Jason Lowe are thanked for comments on an earlier draft.

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