Using the Implementation Centric Evolving Climate Change Adaptation Process to bridge the gap between policy and action

Article

Published Version

TYPE Original Research
PUBLISHED 06 October 2023
DOI 10.3389/fclim.2023.1197027

OPEN ACCESS

EDITED BY
Sirkku Juhola,
University of Helsinki, Finland

REVIEWED BY
Bruce Currie-Alder,
International Development Research Centre (IDRC), Canada
Joseph Daron,
Met Office, United Kingdom

*CORRESPONDENCE
Cathie A. Wells
✉ cathie.wells@reading.ac.uk

RECEIVED 30 March 2023
ACCEPTED 13 September 2023
PUBLISHED 06 October 2023

CITATION
Wells CA, Saggioro E, Petty C and Cornforth R (2023) Using the Implementation Centric Evolving Climate Change Adaptation Process to bridge the gap between policy and action. *Front. Clim.* 5:1197027.
doi: 10.3389/fclim.2023.1197027

Using the Implementation Centric Evolving Climate Change Adaptation Process to bridge the gap between policy and action

Cathie A. Wells*, Elena Saggioro, Celia Petty and Rosalind Cornforth

Walker Institute, School of Mathematical, Physical and Computational Sciences, University of Reading, Reading, United Kingdom

With climate impacts increasing in both frequency and intensity and unprecedented climate events having devastating results, the need for timely policy and action to support adaption is not in doubt. However, the gap between policy and action leaves many communities exposed to extreme events and vulnerable to loss of life and livelihoods. This is partly due to the difficulty policymakers face when confronted by climate projections with their inherent uncertainties. Competing sectoral interests and a lack of resources often compound such challenges. To address these issues, the Implementation Centric Evolving Climate Change Adaptation Process (ICECCAP) encases the climate risk assessment in an enabling framework to track resource, knowledge and regulatory needs. This process was applied as part of a UNEP project to support the National Adaptation Plan in Pakistan. A range of climate storylines, describing plausible climate futures and their potential environmental and socio-economic impacts, were developed and discussed with local stakeholders, including policy makers from across levels of governance. The process allowed us to translate complex physical science into narratives that could be communicated clearly to non-technical national stakeholders, forming a basis for subsequent negotiation and decision-making at a local level to address multiple risks and respond to adaptation needs at this finer resolution. This reflects our aim, as part of the My Climate Risk network, to amalgamate bottom-up climate risk assessment with climate projection data that remains meaningful at a local scale. We show how the integration of scientific research and local expert stakeholder views can promote buy-in to adaptation planning. Grounded in a systemic and comprehensive understanding of potential impacts of climate change, this process has implications across socio-economic, environmental and governance spheres.

KEYWORDS

adaptation, capacity building, bottom-up planning, enabling environment, implementation, decision-making, climate risk assessment

1. Introduction

There is now more than a 50% likelihood that global warming will reach or exceed 1.5°C by 2040, even under very low emission scenarios (Portner et al., 2022). A more ambitious approach to climate change adaptation is needed if progress is to become not just sufficiently rapid, but also widespread enough to reach the areas most in need. According to

Portner et al. (2022), Co-Chair of the working group on Impacts, Adaptation and Vulnerability of the Intergovernmental Panel on Climate Change, there is a "brief and rapidly closing window" for climate adaptation, if a "liveable and sustainable future for all" is to be ensured. If the world continues to react to climate events without proactively trying to reduce vulnerability and exposure and improve resilience, then there is likely to be large scale climate migration, bringing in its wake still more dramatic water scarcity, food insecurity, and global tension (UNHCR, 2021). Arribas et al. (2022) warn of "catastrophic, systematic failures" in climate adaptation if urgent improvements in the way we assess climate risk are not made, but risk assessment is not the end of the story. Adaptation needs refocusing to reflect the barriers that must be overcome in order to implement policies. These barriers are referred to as "soft adaptation limits" and it is only when the adaptation process acknowledges the challenges being faced that progress toward implementation can be made (Portner et al., 2022). This means not just creating a thorough risk analysis, but simultaneously defining precise transformational actions, assigned to key stakeholders, that will allow barriers to be overcome.

Asia in particular is facing a future of heatwaves, droughts, monsoon variability, floods and accelerated glacier melt (Shaw et al., 2022). In this paper we will highlight a new approach to adaptation planning, illustrating the method with an initial case study from Pakistan, one of Asia's most climate sensitive countries and an area where the Walker Institute has been supporting the planning of national adaptation programmes (Azour and Duenwald, 2022). One of the key difficulties in dealing with global warming is that it is just that, a global problem. Producing joint transboundary adaptation plans, however, even between the most co-operative nations, can be perceived as a threat to sovereignty likely to incite a domestic backlash (Butt, 2022). In view of this, a method is needed to standardize risk assessment and adaptation planning, so that the same approach can be applied locally, sub-nationally, nationally and across wider regions. In this paper we describe a first incarnation of such an approach and discuss the benefits and difficulties associated with each stage.

By creating an enabling environment through which to implement adaptation policies, the gaps between current action and necessary levels to reduce risk in the face of an impact can be bridged. According to Portner et al. (2022) up until now the focus has been more on planning than implementation, but in the next decade it is essential that this changes. The UK government, in their 2022 Climate Change Risk Assessment (CCRA), highlights the need to provide sufficient funding, resources, metrics, and research to support adaptation action, but in our case study, it is apparent that ensuring laws and governance are sufficiently robust and providing extra capacity building for local stakeholders is also critical (HMGovernment, 2022). Adaptation needs to become a multi-sectoral, large-scale, cohesive strategy, whereby the involvement of key stakeholders, from ministry level to representatives of vulnerable local groups leads to implementation (Bhave et al., 2016). This will only happen if soft adaptation limits are addressed by enabling changes to funding, laws, data and technology needs, science, capacity building and resources in parallel to the risk assessment framework.

CCRA plays a vital role in deciding what will be the most effective adaptive path to take, whilst also helping nations to avoid maladaptation, in which an action taken for the right reasons has unintended negative consequences (Portner et al., 2022). CCRA is not a new idea and much work has been completed on the refinement of numerical tools based on global data sets and geographical surveys to assess risks of hazard events to critical infrastructure (Fu et al., 2020; Hawchar et al., 2020). These assessments, usually including high level information and regionally down-scaled climate projections, appear to be quantifying risks fully, but often this approach neglects important aspects of vulnerability that can only be captured by qualitative data (Bercht, 2021). Wilby et al. (2009) and Weaver et al. (2013) concluded that in addition to the perceived necessity of developing climate forecast tools, there is also a need to improve the assessment of social and economic vulnerability. Barde et al. (2023) argue that until climate projections are less uncertain they cannot be used for decision-making, but Lemos and Rood (2010) are keen to emphasize the importance of not looking for a single perfect forecast, but "integrating projections into broader decision environments". In applying Robust Decision Making (RDM), Bhave et al. (2016) suggest the use of a range of strategies to address uncertainty such as Dynamic Adaptive Policy Pathways, which use short and long-term projections to guide immediate adaptation with alternative pathways at certain key switching points to take into account the range of uncertain future changes to climate (Haasnoot et al., 2013).

Estimating future adaptation needs from a climate projection approach alone can lead to maladaptation, especially if the climate focus does not allow for a synergy of top-down and bottom-up strategies (Wilby et al., 2018; Arribas et al., 2022; Olivares-Aguilar et al., 2022). An important example of this is the Mirani Dam Project on the River Dasht in Pakistan, which whilst built to harvest flood water and provide much needed irrigation for the area, actually led to a severe backwash flood in 2007, primarily because developers did not consult local experts (Jehangir, 2018). Effective adaptation aims to find measures that will improve resilience and reduce vulnerability in any plausible future (Azour and Duenwald, 2022; Petty et al., 2022). In all decision-making based upon uncertain data, there is a need to "minimize regret" by considering a full range of possible future scenarios and how they will impact systems at varying reference times, whilst bearing in mind the likely skill of the climate projections being used (Lemos and Rood, 2010; Conway, 2011; Weaver et al., 2013). Marshall (2014) suggests that uncertainty can stall action on climate change, whereas tapping into resources of local knowledge helps to tailor adaptation to specific needs. Including stakeholders from associations and organizations outside of state, business and academia not only allows local and indigenous knowledge to inform strategies, but also increases awareness of methodologies being used (Bhave et al., 2016; File and Derbile, 2020; Taylor et al., 2020).

Currently there is too often inadequate adaptation action taken due to underestimation of the severity of the climate impacts being faced, when decontextualized data weakens the predicted intensity of effects or the language of uncertainty leads to different interpretations of risk severity (Jack et al., 2020; Shepherd, 2021). RDM can address the need for low regrets adaptation based on climate data, but Bhave et al. (2016) warn that there is also a risk of extreme events not being captured, with instead too much emphasis being placed on day to day risks. The inclusion of context specific information in climate risk assessment has been found to be critical in informing decision-making on adaptation (Cornforth et al., 2020; Taylor et al., 2020). In infrastructure projects and disaster preparation, it is key to plan for wide ranging scenarios, even those that appear to be the least probable (Dvorak et al., 2020). Where extreme events must be considered, using ensembles of climate models will often average out effects, leading to a lack of preparation, whereas using an event-based storyline can allow exploration of a plausible, if not probable, climate impact (Sillmann et al., 2021). Research into the use of climate storylines to present information by expressing multiple plausible futures, has helped to reduce confusion caused by uncertainty in quantitative scientific data (Shepherd, 2021; Young et al., 2021). Going one step further these physical climate storylines can be used to generate Inclusive Consultative Integrated Climate, Livelihoods and Environment storylines (ICICLE storylines), by incorporating quantitative data from sector specific modeling, such as livelihood analysis and crop models, as well as qualitative data where relevant.

These findings justify the need for the Implementation Centric Evolving Climate Change Adaptation Process (ICECCAP) outlined in this paper. By encasing a mechanism for assessing risk within the enabling environment, which provides a framework for overcoming implementation barriers, it is hoped that policy-makers feel better equipped not just to make vital decisions on adaptation planning, but also to ensure timely action is taken. This is not a one-off process, but a continuous cycle in which the focus on implementation allows higher resolution data to be incorporated into models at each iteration, thus allowing adaptation decisions to evolve. This paper is set out in five sections. In Section 2, ICECCAP is introduced using the enabling environment as a lens through which to view both top-down climate projections and a bottom-up localized stakeholder view of vulnerability, exposure and resilience in order to make important policy decisions. This reflects the ethos of the My Climate Risk Lighthouse Activity, in working from the needs of the decision-makers (WCRP, 2023). Section 3 describes the first use of this approach in Pakistan as a case study of the first iteration of such a process. The project scope and level of stakeholder engagement show that further iterations will still be needed, but that this initial cycle has already identified many of the soft barriers that will need to be addressed. The need for changes to be made in the global approach to adaptation planning is discussed in Section 4. Finally, lessons learnt and recommendations for future application of these methods and analyses are given in Section 5.

2. Practical approach via ICECCAP

Climate risk assessment is often the first step toward creating adaptation policies, but using our Implementation Centric Evolving Climate Change Adaptation Process (ICECCAP) we start by introducing the enabling environment. Once this has been initiated, then we advocate the parallel application of Inclusive Consultative Integrated Climate, Livelihoods and Environment storylines (ICICLE storylines) to incorporate uncertainty inherent in different future scenarios and from a range of climate models with information on possible socio-economic impacts. The whole process is shown in the flowchart at Figure 1. This movement away from physical science analysis leading CCRA is intentional, with climate modeling part of a broader process, which has at its heart a two-way information flow between interdisciplinary researchers, informed by subject specialists, and stakeholders from ministry to community level. It is expected that those leading such research would have experience of a wide range of aspects of climate change adaptation from a scientific, social, and policy perspective and could be from academic institutes or other non-governmental organizations. Global climate services, are also vital in providing information that may be difficult to access in country. Although ICECCAP may appear to be like frameworks described previously for enabling adaptation, such as that given in Conway et al. (2019) and Jack et al. (2020), there are key differences. As in other models, stakeholder information is used alongside climate data, but here, unusually, we use it to choose climate indices to be examined, thus avoiding a disjoint between top-down and bottom-up understanding of future projections. This means that socio-economic changes can be viewed alongside changes due to climate and not as a separate entity. However, the main novelty of ICECCAP lies in using the enabling environment as a focus for all decisions from the start of the process, so that barriers to implementation are considered before plans take shape. In addition, we acknowledge from the beginning that this is an iterative process, with the potential for further development at each cycle. At the first phase quantitative socio-economic modeling may not be possible, but as funding, capacity, research, resources, governance, and data are all built up through the enabling environment, a more granular level of detail can be included at each iteration of the process.

2.1. Enabling environment

According to a recent United Nations Environment Programme (UNEP) report, 120 out of the 154 countries considered are launching a process for addressing adaptation gaps, but only 10 of these are currently implementing and managing the actions described in their National Adaptation Plans (United Nations Environment Programme, 2021). The gaps between policy and implementation in both climate change adaptation and education about it can often be traced back to a lack of accountability, resources, funding, data, capacity, and research (Mbah et al., 2022). For example, in Pakistan incorporating nature into urban planning could improve sustainability of water management and enhance cityscapes, but limited by a lack of climate specialists, too often these chances are missed and instead outdated approaches continue (Hafeez, 2022). In more recent academic literature there is now a heavy emphasis on adaptation gaps, particularly since 2015, but very little material can be found discussing how targeted action could identify and begin to address barriers preventing implementation of carefully developed adaptation policies (Lee et al., 2022). Our system requires the enabling environment to be developed in tandem with risk assessment, so that these barriers are considered before

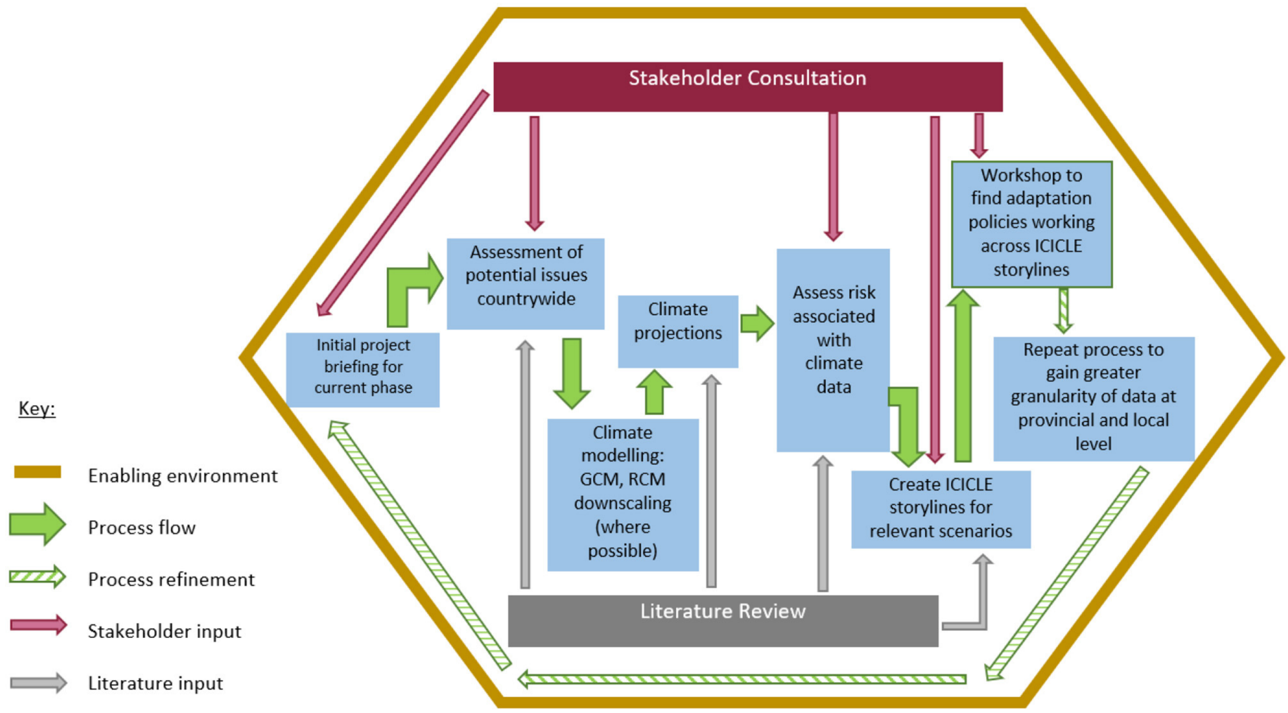

FIGURE 1
Flowchart of the Implementation Centric Evolving Climate Change Adaptation Process (ICECCAP).

adaptation policies are created. It is imperative that any barriers to implementing policies are highlighted and overcome at the outset. The key innovation in our methodology is the use of an enabling environment hexagon (shown in Figure 2) which allows potential soft barriers to adaptation to be classified quickly into six different sections, so that effective steps toward removing barriers can be incorporated into plans. This provides a strong, transparent framework that will help stakeholders to understand and engage in the process, which is imperative, given that benefits from adaptation projects are often not seen for a decade or more (Portner et al., 2022). We identify the key gaps in implementation of adaptation strategies both by examining literature based on reviews of a range of adaptation projects and through discussion with stakeholders. In Portner et al. (2022), it is stated that the key components needed to ensure climate resilient development are inclusive governance, investment and finance, access to appropriate technology and capacity building at all levels. We believe that these are also among the factors that can bridge the gap between adaptation policy and implementation. We also identified availability of resources and key scientific research as imperative in selecting and implementing the most effective adaptation routes. In the following sections, the six elements of the enabling environment are described.

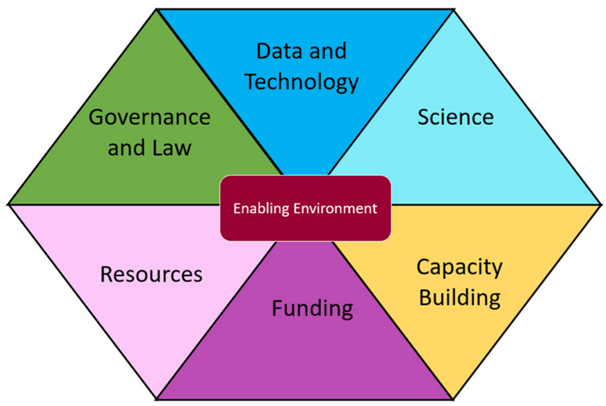

FIGURE 2
The enabling environment diagram structure.

2.1.1. Governance and law

Governance in climate adaptation is vital. According to a 2017 review, 170 countries include adaptation somewhere in their policies, but of these only 91 have any laws associated with this important area (Nachmany et al., 2019). If a commitment to adaptation is visible at the highest levels of governance, then this tends to be incorporated at an institutional level too, but forming policies to cope with climate change requires a culture change in the way political decisions are made (Gogoi et al., 2017). Sometimes it is necessary to take unpopular action to deal with long-term risks, far outside of the electoral cycle timing, such as in the case of relocating communities who are currently in areas exposed to flooding or ensuring that future development does not encroach on drainage resources (Gogoi et al., 2017; Ferris and Weerasinghe, 2020; Akbar et al., 2022). Although in some cases strong national level climate adaptation governance is in place, at a regional and community level this tends to be fragmented and *ad hoc*, with only 50% of policies including some form of delegation to local government (Gogoi et al., 2017; Nachmany et al., 2019; United Nations Environment Programme, 2021). Specific regulations concerning particular sectors are also very important. For example in Pakistan, improvement of water resources will require stronger regulations on pollution management, groundwater pumping and irrigation. Often these regulations are difficult to enforce, but careful balancing between regulation and incentives, can help. It is also worth noting that a lack of co-ordination between different ministries and institutions within a country has been flagged as the most critical barrier to implementing adaptation initiatives (Mimura et al., 2014; New et al., 2022). It is, therefore, critical that the enabling environment includes a map of all involved in regulations and ensures that there is no contradiction between approaches.

2.1.2. Data and technology

Data is needed not only as a baseline to justify adaptation, but also as the evidence base for monitoring, where adaptation is to be evaluated (Gogoi et al., 2017; New et al., 2022). If data is lacking, whether it is climate or socio-economic information, the scope of an adaptation policy can be limited, so it is important to note necessary data-based evidence requirements from the outset (Kapoor et al., 2021). In low-income countries like Pakistan, there are often gaps in data due to lack of monitoring stations, poor management of data feeds and interruptions to data gathering (Bhave et al., 2016; Ali et al., 2019, 2021; Hassan et al., 2019). By acknowledging these issues at the outset, adaptation budgeting can be used to improve systems and access pathways to avoid implementation barriers at a later date. With the setting up of the World Meteorological Organization's Global Framework for Climate Services, there has been much progress on supporting data needs globally, with a focus on health, water, energy, food security, and disaster preparedness. However, according to Cao et al. (2022), climate services are becoming increasingly "technocratic," rather than investing in the free proliferation of data, so new ways to record and process information to aid a more people-first approach must be found. Any data which is flagged by stakeholders in the initial briefing meetings can be sourced as the process unfolds, or else funding sought to provide it in the next iteration of ICECCAP.

2.1.3. Science

Research and development appears in the adaptation framework of 80% of countries according to Nachmany et al. (2019). As more diverse stakeholder engagement is sought, to ensure buy-in to adaptation planning, so the need for user friendly climate risk information becomes ever more important (Gogoi et al., 2017). This means that not only must the research be completed, but it must also be widely disseminated. However, this is not merely a consideration for climate modelers. Within the scientific analyses undertaken, the emphasis must be on interdisciplinary research. Even within the sphere of physical science there is a need to integrate experimental and modeling approaches from a range of disciplines when researching climate change, as its effects cannot be neatly compartmentalized (Gornish et al., 2013). Nonetheless, an understanding of the natural processes involved is not sufficient to make useful decisions on adaptation; insights from the social sciences are needed to inform what Fouqueray and Frascaria-Lacoste (2020) call "an integrative and interdisciplinary science for adaptation". With the synergy of top-down and bottom-up methods shown to be most effective, there is a need to combine indigenous, local and scientific knowledge, which can only be done if outstanding research and information gathering is completed early in the process (Portner et al., 2022). A good example of an area where combining science with local expert knowledge is sometimes neglected in the adaptation process is in crop research and development. Whilst there has been much scientific exploration of the effects of the changing climate on agricultural yield, adaptation planning needs to be informed by increased analysis of specific new crop options at a more local level (Niles et al., 2020). This, in turn, must be contextualized by a full understanding of the local livelihoods model, including information on the vulnerability of all sections of the local communities to changes in agricultural practice (Etana et al., 2021). If such research is lacking, then this should be highlighted and funded, rather than having an adaptation policy that just pledges to grow more climate resilient crops. Continuing to make recommendations without having considered enough local information to be specific about adaptation options, will not only hinder implementation due to a lack of key details, it will also have implications for any funding decisions made.

2.1.4. Capacity building

Capacity building is a vital part of all adaptation planning, particularly as the countries most in need of adapting to climate change often have the least institutional capacity to ensure these changes are made (Bellon and Massetti, 2022). It has been shown that investing time early on in creating a small group of committed and engaged officials, who can become policy champions, spreading the message of climate change adaptation, is extremely valuable (Gogoi et al., 2017). Where the building of capacity is included in adaptation planning, implementation depends to a great extent on the expertise of those providing training, which can sometimes be too limited to allow confident proliferation of knowledge (Fullwood-Thomas and Saqlain, 2017; Nachmany et al., 2019). However, there are options available to gain climate related-support to develop capacity from external agencies (Bellon and Massetti, 2022). For example, the World Climate Research Programme (WCRP) My Climate Risk Lighthouse Activity aims to encourage both knowledge and capacity exchange between hub organizations in different countries to ensure that local stakeholders have the contextual information and scientific understanding to be at the forefront in adaptation decision making (Blair et al., 2022; Cao et al., 2022; WCRP, 2023) (This is discussed in more detail in Section 4.). Via the enabling environment, the need to work with such organizations in order to aid capacity building at an institutional, community, and individual level can be signposted at the adaptation planning stage.

2.1.5. Funding

More than ever, it is recognized that funding is vital in ensuring that climate adaptation policies are actually implemented (New et al., 2022). However, allocated finance and necessary investment are steadily growing further apart (New et al., 2022). For developing countries, where the largest contribution to climate change adaptation must be sought externally, it is imperative that soft barriers to implementation in this sector are noted and overcome, with the availability of international climate finance a major catalyst in increasing the likelihood of policies being implemented (Gogoi et al., 2017; New et al., 2022). Governments often limit investment in risk reduction, due to many of the reasons mentioned in Section 2.1.1, but the private sector prefers low risk investment, so initial public sector funding of projects to reduce risks, may well encourage subsequent private investment (Nachmany et al., 2019; United Nations Environment Programme, 2021). However, within this structure it must also be recognized that extra finances used for adaptation projects, could result in instability due to increased levels of debt. This balance between ensuring economic stability and future proofing against climate risks will need to be carefully managed by those in power (Hallegatte et al., 2020). Although in a perfect world, available finance would be dependent on adaptation planning, in reality the reverse is often true.

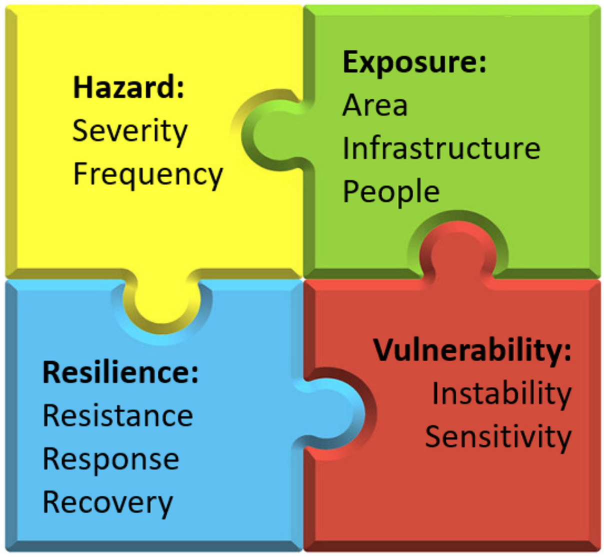

FIGURE 3
The four elements used to determine climate risk.

2.1.6. Resources

Resources can have many meanings, but in this context we consider both physical objects and institutional services. These are particularly important in poorer communities, where when basic needs are not met, adaptation strategies are rendered unlikely to succeed (Hallegatte et al., 2020). Investment in resources beyond Early Warning Systems is often neglected in planning for adaptation and yet, if resources are lacking, progress will falter (Nachmany et al., 2019). In Pakistan, for example, health resources needed include improving mental health services for those that have been traumatized by repeated extreme climate events and also providing assistive devices for people with disability at climate emergency response centers (Iqbal, 2020; UN Office of the High Commissioner for Human Rights, 2020). It is impractical to plan adaptation strategies whose resource requirements are not realistic, but equally limiting the scope of projects to fit current resources may lead to unambitious and less effective actions (Hallegatte et al., 2020). Planning needs to optimize resource use, particularly where these resources are scarce (Bellon and Massetti, 2022). One way of doing this is to adopt a dynamic adaptation planning approach, one in which plans can be updated as resources become available, with the resources needed to unlock these different pathways being recorded as part of the enabling environment (Bhave et al., 2016; New et al., 2022).

With the enabling environment fully defined, we now move to the description of the risk assessment process, remembering that finer levels of detail will be added to the enabling environment hexagon at each stage and as each potential barrier to risk reducing adaptation is noted.

2.2. Defining risk

Risk is generally assumed to be well-understood in the climate change community, but in evaluating the treatment of risks and uncertainties in IPCC papers, Aven and Renn (2015) found that although improvements have been made there is still a lack of precision in definitions of the key terms used in CCRA. The IPCC defines risk as the "potential for adverse consequences" which can result from "dynamic interactions between climate-related hazards and exposure and vulnerability", where vulnerability is a measure of how predisposed people and infrastructure are to climate impacts and exposure is how physically close they are to sources of climate hazard (Portner et al., 2022). In our methodology, however, we also include a fourth element, resilience or the ability to recover without loss of assets or physical infrastructure after a disaster, in the measurement of risk. Often action to increase resilience is prompted by recent impacts, but this can narrow its efficacy, whereas by considering a wider range of possible climate events, a more comprehensive approach can be taken (Portner et al., 2022). When viewed in the broader context, it can be seen that building resilience by actions such as improving capacity or increasing resource effectiveness, will also reduce vulnerability (New et al., 2022). This is becoming steadily more important as climate events become more frequent, one impact often compounding the challenges brought by the next. Figure 3 illustrates these four elements which help to establish the threat posed by any given risk. Whilst natural climate hazards are unlikely to respond in the short term to direct local intervention, they may be reduced over longer periods by global mitigation efforts. Exposure and vulnerability, however, can be reduced by local action with immediate results, just as resilience can be built by working from the bottom-up, referencing the practical experience of national, provincial and district stakeholders.

2.3. Cross-level stakeholder mapping

It is important to engage stakeholders in the risk assessment process as early as possible, as adaptation action plans are far more likely to be embraced by communities that have helped to design them (Taylor et al., 2020). Solutions have also been shown to be more effective where scientific theory is coupled with indigenous and local knowledge (Portner et al., 2022). Knowing relevant information about the vulnerability of livelihoods for one local group or the predisposition to flooding of a particular small area are key in creating made-to-measure adaptation strategies, rather than relying on a “one size fits all” approach that is dictated by global climate model projections alone. Where data is missing, it is also becoming increasingly accepted that expert knowledge can be used to help create causal models, quantified from a combination of participatory judgements and data from different disciplines (Mayfield et al., 2023). Use of local knowledge to improve and refine climate storylines and risk assessments is not only both effective and cost efficient, but also prevents adaptation strategies being too narrowly focused (Bercht, 2021).

From the flow diagram of the whole process shown in Figure 1, it can be seen that stakeholders have an input to every part of the cycle, save the climate projection modeling itself. Their opinions will shape the project brief, add important local context to potential issues affecting exposure, vulnerability, and resilience, they will influence the choice of the most relevant climate indices to analyse, shape the ICICLE storylines based on their experience and help to populate these with risks associated with each part of the climate projection summary. Finally it is down to the expertise of the stakeholders to decide which adaptation policies will be most effective. As ICECCAP progresses, stakeholders and project facilitators, will be continuing to deduce what implementation barriers may exist and to work out how these can be overcome. As more data, research, funding and resources become available or as new governance procedures are put in place and capacity is built, then the process can be revisited with a finer resolution of climate modeling and more granularity in sectoral modeling of physical processes such as crop yields and hydrological analysis. The flow diagram given in Figure 1 looks at starting with a general, often national, picture and repeating this at sub-national and local scales. Equally, there may be funding for only one geographical area to be examined in detail at first or certain interconnecting sectors to be considered, then gradually results of this initial application of ICECCAP could be used to inform the next iteration of the process across a similar area. However, although scaling solutions that work is often seen as a way to tackle adaptation quickly and in some cases this can be effective, it is imperative that this does not ignore vital differences between regions, leading to maladaptation (Bowcott et al., 2021; UNFCCC, 2021).

It is clear that stakeholders are key to ensuring the relevance of all analysis undertaken, but who do we mean by stakeholders? Groups involved in adaptation planning should be varied and wide ranging, thus the reason for ICICLE storylines being described as using “inclusive consultation”. Whilst government ministries are often involved in commissioning such projects, non-state actors from all backgrounds have an important part to play in increasing resilience against climate impacts. For example, public-private partnerships in engineering projects, healthcare and even food production can all make a difference (Taylor et al., 2020; Bowcott et al., 2021). Governments, the private sector, climate services, academia and civil society must all be involved if progress is to be adequately rapid and support populations inclusively, giving a voice to all, even the poorest and most vulnerable (Portner et al., 2022). Unfortunately it is not always possible to access such wide groups of stakeholders, as became apparent in our first ICECCAP cycle in Pakistan, meaning that results will need to be enhanced at the next iteration of the process to ensure their local relevance.

2.4. Assessment of key research goals and challenges

The focus for risk reporting should be decided by careful consultation with stakeholders, reinforced by a thorough examination of available literature. In practice the stakeholder involvement may be limited in the initial stages of ICECCAP, but the most extensive local stakeholder consultations that can be achieved in-country should be undertaken, with potential for fact finding missions in some cases. Important cross-sectoral issues must be dealt with, but the creation of the risk assessment will not usually have the scope for new and protracted research projects. Instead, being able to use what is available, whilst signposting areas where more research could add value to future iterations of the assessment is the most resource and time efficient way to proceed. This should be recorded as part of the enabling environment so that adaptation plans include alternative branches as more information becomes available at later iterations of the process.

To illustrate this assessment of potential issues we can use the example of the decline in crop yields and livestock rearing across Asia. These effects are likely to escalate food insecurity, with different impacts in different regions, but they are not the result of a single climate hazard (Shaw et al., 2022). For example, Pakistan has had a recent history of droughts and floods both of which can destroy vast areas of crops (Waseem et al., 2022; Qamer et al., 2023). Equally lack of drainage and higher temperatures have important health consequences for livestock and fodder production. Sea level rises can cause inundation of previously fertile land and leave communities with nowhere to grow crops or graze livestock. Increased evapotranspiration caused by higher temperatures also affects agricultural productivity. This network of cascading causes and effects will need initial mapping so that climate projections can be looked at in context, by the selection of issue-appropriate climate indices and in some cases specific eco-regions, defined here as “ecosystems of regional extent” (Dinerstein et al., 2017). Before embarking on analysis of future climate projections it is also very useful to compare current climatic conditions with records from historic periods, so that the results of climate change that are already evident can be considered, along with recorded levels of exposure, vulnerability, and resilience based on both quantitative and qualitative data.

2.5. Climate projections

Once key areas of concern have been raised, then it is important to examine climate projections. Too often use of climate data has failed to take into account the views of those directly affected by

10.3389/fclim.2023.1197027

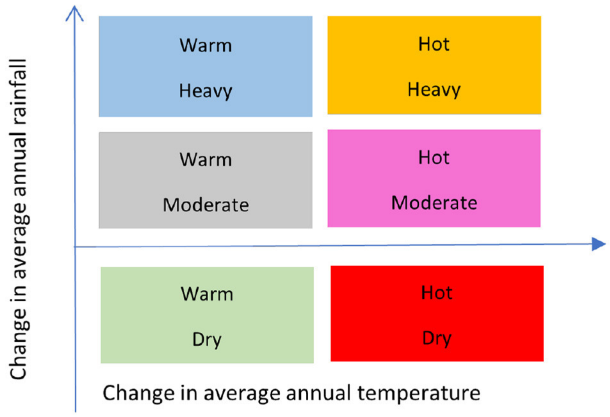

FIGURE 4
Climate change matrix model for possible changes in temperature and rainfall.

changes, mismatching with locally collected survey or workshop information in terms of both temporal and geographical scale differences (Conway et al., 2019). However, examining climate projections should not be looked upon as a separate process, as the choice of climate indices and projection timescales should be guided by bottom-up engagement, so the much needed integration between top-down and bottom-up approaches is addressed. Depending on the project scope, this may mean using data that is already universally available, or it may require specialist techniques to downscale data either dynamically or statistically to specified regions. The key to this work is the inclusion, whatever the source of the projections, of multiple scenarios, a range of climate models and different timescales. In this way a full range of futures is considered, thus reducing the emphasis on uncertainty in any one dataset.

Plotting bivariate data drawn from two key climate indices for a country and then charting regions of change, for example allows model and scenario uncertainty to be summarized for use in climate storylines (van den Hurk et al., 2014). Although this does not capture all relevant dimensions of change, it allows the main storylines to be generated and makes continuing communication with stakeholders more straightforward through the simplification of the uncertainty achieved. Figure 4 shows one possible mapping of regions on a graph of change in average annual temperature against change in average annual rainfall. Later in the case study section (Section 3) this method is applied to Pakistan. The change regions are shown, along with the projection data linked to different climate scenarios and different time periods, in the example from Pakistan given in Figure 7. Some sections of the chart may have very few data points, so depending on time and resources, it may be decided to work only with the climate scenarios meeting with most agreement between climate datasets. By clarifying the most populated areas on the axes in this way, a distinction between key climate storylines is provided a priori. However, the eventual aim should always be to investigate all possible scenarios, not just the most likely.

2.6. Assessment of vulnerability, exposure and resilience

Vulnerability, exposure and resilience to the key climate changes highlighted by climate storylines can now become a focus. There are many creative ways to engage with stakeholders from using the media of art, theater, and dance, to co-producing short films, all of which can be valuable tools in building a good working relationship. However, when research must be undertaken more remotely, questionnaires or guided discussion groups involving a full range of stakeholders and further literature review can also be used.

One way to gather views is for stakeholder questionnaires to be created with a first section of four or five questions covering the key topics being investigated, for example what they perceive to be the main sources of vulnerability in their community or which agencies are involved in CCRA in their region. These lead to later groups of more specific inquiries within these same topic areas, such as whether action is being taken to reduce any of the vulnerabilities they have mentioned and how successful any such schemes have been or whether the respondent has personally been involved in local CCRA reports and how these have been applied. Given that adaptation planning in low income countries is often conducted by non-local consortia, via United Nations agencies, it is important to note that these questions should be posed in the local languages and adapted to the local culture.

Another approach is to use local facilitators to arrange guided discussion groups, based on questions provided by researchers, but allowing for a more general and open-ended dialogue. Stakeholders are encouraged to answer as fully as they are able to and elaborate further where they feel this is pertinent, including references to any reports or experiments in which they may have been involved. Summary notes of guided discussion group sessions are compiled by the meeting facilitators for the researchers, anonymizing the participants. However, where particular participants are eager to engage further with the process, facilitators are encouraged to provide contact details to allow further one-to-one discussions. In organizing stakeholder meetings, facilitators will require training to help them manage discussion technique, so that all involved feel free to participate, even given local or traditional social hierarchies. Equally cultural considerations are vitally important when discussing attitudes to gender and disability, so that all views are valued. Representatives of specific groups, for example based on gender, health and poverty are often those best placed to discuss climate change vulnerability, as this can be increased for female and transgender citizens, those with disabilities or poor landless, community members (Human Rights Council, 2020; Idris, 2021; Portner et al., 2022).

2.6.1. Historic disasters

Even once those most vulnerable to disasters have been identified, the level of impact likely to be caused by this vulnerability may be harder to ascertain. One way to understand better the likely magnitude of climate change hazard effects, is to research previous disasters. By considering not just which disasters have occurred when and where, but also what conditions led to them occurring and how many people, hectares of crops, villages etc were affected, scope of future impacts can be estimated. This is also useful for evaluating adaptation effectiveness, as the result of one climate event in the past can be compared with a similar event after implementation of measures to reduce exposure and vulnerability. However, it should be noted that any changes to socio-economic conditions between these climate events must also be considered. In-country disaster databases may be accessible, but otherwise the EM-DAT global database is universally available, as are aid agency gray literature reports, all of which give a useful level of detail (CRED/UCLouvain, 2022; OCHA, 2023).

2.6.2. Charting risk more locally

A number of datasets may be available for a particular region, charting various risk indicators. Potential indices include numbers of people likely to be exposed to a particular hazard, as well as socio-economic data on poverty, literacy and population density at a local level. If this data is not available specialist stakeholder workshops can be held to elicit expert guidance. By charting local level data, a ranking for regions needing urgent adaptation measures can be found, allowing prioritized action. In avoiding the production of a single figure to express risk, useful details on vulnerability to specific hazards is not lost. Thus an area with a need for agricultural extension services to help reduce exposure to water and food scarcity, can be identified from figures on crop yields, malnutrition figures and rainfall deficits.

2.7. ICICLE storylines and infographics

A storyline provides a framework that ensures responses are best fitted to needs. They are defined in Shepherd et al. (2018) as:

> a physically self-consistent unfolding of past events, or of plausible future events or pathways.

Taking into account the considerable range in definitions of climate storylines, we introduce here ICICLE storylines, which enhance climate storylines with socio-economic information from expert sources and from robust scientific analysis, such as hydrological impact modeling. Whilst similar to the climate risk narrative, as discussed in Jack et al. (2020), these include cross-sectoral analysis and quantitative socio-economic modeling at increasingly more granular levels at each iteration of the process. In this way climate data is not regarded as a distinct entity, but is augmented by layers of information derived from stakeholder, scientific and literature input to describe some of the effects that changes in the climate may have on those impacted. ICICLE storylines are of particular use to regions like South Asia in which adaptation has so far tended to be reactive (Shaw et al., 2022).

Climate storylines are useful in the first instance in preventing the need for presenting raw climate data and the associated large and uninformative uncertainty ranges to decision makers. Such projections, including levels of uncertainty cascading to the local scale, can seem to undermine the effectiveness of any adaptive action (Hawkins and Sutton, 2009; Wilby and Dessai, 2010; Young et al., 2021). For the most part these uncertainties fall into four main groups:

1. Uncertainty based on unknown future socio-economic pathways and levels of emissions,
2. Uncertainty inherent in climate models used to make climate projections,
3. Natural variability of the climate system,
4. Sensitivity of people and systems to climate change.

By using a range of storylines to show distinct pathways, uncertainty can be more fully represented (Young et al., 2021). Climate storylines have been used in several contexts to bridge the gap between uncertain climate projections and detailed local knowledge (Shepherd, 2021). By integrating climate storylines giving scientific data with social, economic and cultural factors, ICICLE storylines can be formed. Stakeholders have a vital role here, in continuing to populate each plausible future scenario with further contextual information, linking the quantitative shell, with its initial idea of climate impacts, to current localized socio-economic data. In this way the "best estimates" of climate science can be made meaningful to a wide audience (Shepherd, 2021). For example, from ICICLE storylines based on both quantitative and qualitative data, decision-makers will have enough evidence about possible futures to feel confident in intervening with less fear of maladaptation (Young et al., 2021; Portner et al., 2022). Looking at several plausible physical climate storylines, leading to different versions of ICICLE storylines, allows a deeper understanding to replace unrealistic quantitative precision. For example, infrastructure changes will be more long-lived if multiple futures are considered, as has been the case with the Thames Barrier in London. Here planning incorporated a range of possible future scenarios so that the infrastructure is adaptable to changes in sea level rise and climate change until the end of the twenty-first century (OECD, 2021).

These enhanced storylines allow futures to be viewed in the context of key sectors, such as health, water resources, agriculture, livelihoods, energy, and land use change (Young et al., 2021). Climate Risk Narratives, as used by Jack et al. (2020), whilst similar do not require this level of impact analysis, although both tools can be used in engaging with stakeholders in order to enable socio-economic contextual expert information to be incorporated into the adaptation process. Event-based storylines are another variation on this approach. These concentrate on just one particular event and use a similar integration of climate models, past events, expert knowledge and specific interactions between hazards, vulnerability and exposure to ensure disaster preparedness. This approach was, for example, used to great effect by the British Government in stress testing flood preparedness by creating an extreme storm scenario (Sillmann et al., 2021). ICICLE storylines incorporate all of these features, but at the same time allow the inclusion of intersectoral interactions across multiple time frames, thus ensuring that decisions embrace a full range of potential risks and serve strategic adaptation planning at a range of spatial and governance scales (Marshall, 2014; Cornforth et al., 2022).

Each climate storyline, therefore, evolves into an ICICLE storyline giving relevant climatic changes followed by an exploration of the associated socio-economic effects. When communicating this material to a wide audience, it is often helpful to create infographics, which provide an easy to digest summary of likely changes and their impacts. These are particularly useful for stakeholder workshops, where experts from a range of different backgrounds can give their own perspectives on what other effects are likely and how adaptation could help. This allows a full understanding to be reached of where adaptation will have the greatest effect and what soft barriers will need to be overcome, so that adaption options are viewed in terms of what is realistically implementable.

2.8. Expected outcomes of ICECCAP

ICECCAP aims to allow in-depth understanding of the specific climate change challenges faced by a nation, region, or community depending on the focus required.

The key expected outputs to this process are:

- To identify soft barriers to implementation and ways to overcome these.
- To engage stakeholders across governmental and non-governmental groups and build capacity for future ICECCAP iterations.
- To identify sources of risk including exposure, vulnerability, and resilience.
- To evolve climate storylines into ICICLE storylines based on expert local information, review of literature and relevant scientific and livelihoods modeling.
- To enable smooth implementation of the NAP process.

Unlike some forms of numerical CCRA used in the past this method does not aim to give a single number to risk (PDMA Punjab, 2022; Sapienza Consulting, 2022). Instead we focus on overcoming the soft barriers that could hinder the implementation of an adaptation policy within our approach, whilst also providing ICICLE storylines, incorporating all plausible future scenarios and a comprehensive review of exposure, vulnerability, and resilience based on stakeholder information and literature.

3. Case study

The case study used here to illustrate an initial application of this process, is drawn from work undertaken in supporting the creation of the National Adaptation Plan in Pakistan (Wells et al., 2023).

3.1. Introduction to the region

Pakistan in South Asia is classified as "highly exposed" and "highly vulnerable" in a report by the International Monetary Fund (Azour and Duenwald, 2022). It is situated in a geopolitically unstable region, with climate issues adding to cross-border tensions (Butt, 2022; Dezfuli et al., 2022). An escalation to food insecurity is imminent across the region, as climate related risks cause declines in fisheries, crops and livestock (Shaw et al., 2022).

In Pakistan and many other nations in the same region, extreme weather and changes in climate patterns are challenging livelihoods, with prolonged droughts, flash floods, and rising sea levels common problems (Chapman et al., 2021; Isaczai, 2022). Pakistan, however, also faces its own unique challenges such as increased cases of glacial lake outburst floods and landslides in its northern region, for which early warning systems and improved vegetative cover are key adaptive strategies (Amin et al., 2020).

Where Pakistan does have an advantage when it comes to planning for adaptation is its young population with approximately 60% of the people aged 25 or under (Hafeez and Fasih, 2018). Although young people are some of the most vulnerable to climate change, studies have shown that they are also more open to embracing new adaptive methods and technologies which are essential in reducing climate risk (Ali and Erenstein, 2017).

Pakistan is already witnessing extreme weather events which are threatening health and wellbeing (Mbah et al., 2022). Many areas across the country are seeing increased rates of vector and waterborne diseases, malnutrition and mental health disorders due to heat, floods, drought, and increasing air pollution. Given the combination of poverty, limited access to services and high dependence on climate-sensitive livelihoods in the region, all of which increase risk, it is unsurprising that mortality levels from 2010 to 2020 have risen by 15 times across South Asia, with larger increases in the most vulnerable countries (Azour and Duenwald, 2022; Portner et al., 2022). Even in the more developed urban areas of Pakistan there is a risk under rising temperatures from the urban heat island effect and increasing sea levels are threatening to inundate coastal cities such as Karachi. Due to a unique combination of geographical, political and socio-economical factors Pakistan is currently facing, "a level of climate carnage beyond imagination", according to António Guterres, Secretary General of the United Nations (Butt, 2022; Mbah et al., 2022).

Despite Pakistan releasing its National Climate Change Policy in 2012 and a framework for implementation in 2013, little progress has been made, save for a few discrete projects mainly based in the provinces of Sindh or Punjab (Parry, 2016). Pakistan has a wealth of documentation on climate change for both the nation as a whole, via the updated 2021 National Climate Change Policy, and for each of the main provinces, Balochistan, Khyber Pakhtunkhwa, Punjab, and Sindh (Water Resources Development Sector, 2017; ECCCDD, 2021; MoCC, 2021; Pakistan Ministry of Climate Change, 2021; EPA KP, 2022). Even at district level risk assessments are in evidence across some provinces. However, the issue seems to be implementation of adaptation policies based on these risk assessments. There is also a limited integration of scientific and socio-economic information, so that barriers to adaptation caused by issues such as poverty, gender and education are noted, but not taken into account in the ambitious policy statements. In 2018 the "Building Capacity to Advance National Adaptation Plan Process" was approved by the Green Climate Fund (Green Climate Fund, 2022). Although due to finish in 2021, delays including COVID led to an extension until June 2023 (Green Climate Fund, 2022). The case study described in this paper is part of this UNEP led project, enhancing adaptation planning in Pakistan and establishing a process by which climate risk assessment and further adaptation planning can be updated on a continuous basis.

3.2. ICECCAP for Pakistan

We now consider how the journey through the flowchart given in Figure 1 progressed with reference to the project undertaken in Pakistan.

3.2.1. Initial project briefing

This step is essential in ensuring that the climate issues most in need of addressing from the perspective of the in-country briefing group are highlighted and that any existing local climate research and adaptation information is available to build upon, to avoid duplication and maximize continuity wherever possible. Adaptation needs to be seen as a participation exercise from the outset. This is also an excellent opportunity to introduce the enabling environment framework and instigate any short-term projects that could add value to the final adaptation outcomes.

Pakistan's initial briefing showed that members of the Ministry of Climate Change were keen to find out about the methodology behind ICECCAP, particularly with reference to tracking the technological, regulatory and research needs that would enable policies to be implemented. As well as an overview of resilience, vulnerability and exposure across Pakistan, a focus on the four main provinces was required with particular reference to water resources, agriculture, health and disaster preparedness. These project foundations were all laid centrally, by consultation with the Ministry of Climate Change, with no participation by other expert stakeholders. In the initial iteration of ICECCAP it is preferable to access views from a wider group to establish a more localized and inclusive forum. However, given the contacts available, this initial briefing was adequate taken with research, particularly from gray literature, to ensure that a full picture of key challenges for all Pakistanis was accessed. Pakistan was keen to embark on a full stakeholder consultation, but without in-country representation, this proved difficult, leading to questionnaire responses arriving too late to shape the initial project and follow-on interviews being very limited. However, from the initial project terms of reference it was possible to agree on a research framework.

3.2.2. Assessment of potential issues countrywide

In looking at some of the most important hazards likely to affect the country, the choice of areas for more detailed subsequent research and the most relevant choice of climate indices could be finalized.

A stakeholder map was created based on past reports, which was then sent to ministerial contacts, so that a suitably wide-ranging response to enquiries could be accessed. An example of a generic stakeholder map is given in Figure 5 which is based on the map used for the Pakistan project (details are sufficiently reduced to allow it to be legible as an illustration). Initial questionnaires were prepared for dissemination to members of this map to obtain a baseline picture of the current situation. The stakeholder map was later enhanced by discussion with those who accessed the questionnaire so that a further attempt could be made to contact more stakeholders directly. Questionnaires included introductory questions on climate change information and adaptation initiatives, with later more detailed sections on each of the sectors identified in the initial briefing. Where stakeholders were contacted directly, after an initial telephone discussion, only the most relevant key sector questions were included in the questionnaires emailed out. Unfortunately the response to all these initiatives was very limited and this shows the importance of a strong initial network, more possible with an in-country presence. Given the scope of the project, however, we were limited to completing a comprehensive literature review of both peer reviewed and gray literature. This flagged potential vulnerabilities and exposure, as well as showing where resilience had already been enhanced by adaptation actions. Only the most recent papers and reports were included, those from within the last 7 years, to ensure that material was as current as possible. It is hoped that the next iteration of this research will include important firsthand community-based stakeholder input, rather than relying on previous stakeholder surveys from literature.

3.2.3. Climate modeling analysis

In order to produce climate storylines, climate data was needed from a range of models, time periods and emissions scenarios.

The context of the Pakistan project was limited, with no scope for new downscaling of climate models to be undertaken. The preferred focus for the Ministry of Climate Change representatives was the provision of a method for future risk assessment on which to base adaptation planning. From the most recent literature it was possible to summarize climate changes that are already in evidence and future projections based on CMIP5 RCMs at a local level and CMIP6 GCMs for a more national overview. To create climate storylines, currently available data drawn from CMIP6 GCMs was obtained from the Climate Change Knowledge Portal, which allowed consideration of both national and provincial projections (World Bank Group, 2021). The choice of climate indices was based on a review of literature and the limited responses from stakeholders. Maximum 5-day precipitation was chosen to give insights into the changing monsoon season. For three provinces maximum number of dry days was examined in conjunction with humidity levels, whereas for the more mountainous province of Khyber Pakhtunkhwa the number of ice days was considered in conjunction with changes to precipitation. In each case the difference between a baseline historical period (1986–2005) and the future time periods (2020-39, 2040-59, 2060-79 and 2080-99) was considered, to correct climatological biases. Scenarios SSP1-2.6, SSP2-4.5 and SSP5-8.5 were included to show a range of plausible futures. Although this approach was not as locally specific as is advised when undertaking ICECCAP, interesting conclusions could still be drawn and the need for downscaled projections was added to the enabling environment to inform the next process iteration.

3.2.4. Climate projections analysis

Once climate models had been accessed, the process of analyzing projections could begin.

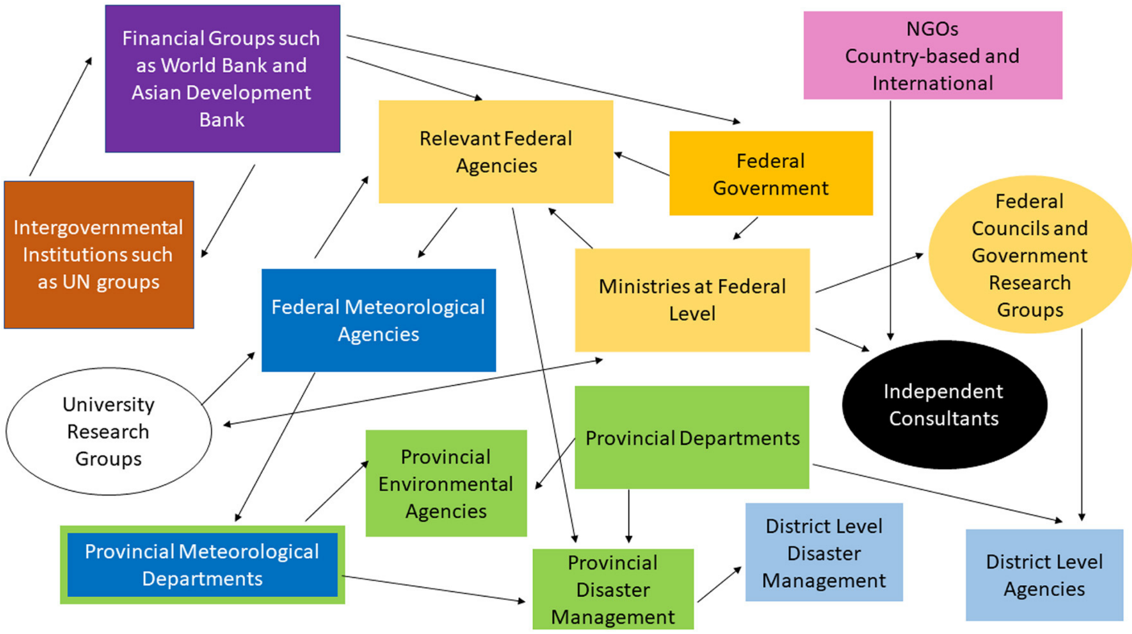

FIGURE 5
Example of a stakeholder map giving key experts in all areas affected by climate change and the perceived interactions between these groups.

The Pakistan data available from the Climate Change Knowledge Portal was averaged over an ensemble of 31 different GCMs, as described in World Bank Group (2021), so median data were plotted, but in the case of maximum 5 day precipitation, whiskers were given at the 10th and 90th percentiles, to give an indication of the spread of results between models. Plots included data based on different climate scenarios and different time periods, so that uncertainty could be incorporated into storylines. An example of these charts is shown in Figure 6.

Scatter diagrams were also created to show the relationship between days with a dangerously high heat index and maximum number of consecutive dry days for Punjab, Sindh, and Balochistan, whilst for Khyber Pakhtunkhwa climate indices of percentage change in precipitation and change in number of ice days were more appropriate. In the scatter diagrams, an example of which is given in Figure 7, points are displayed to show results for different climate scenarios, different seasons and different time periods. In this way general trends including the uncertainty caused by these effects could be taken into account when creating each ICICLE storyline.

By showing the range of future climate projections from the CMIP6 generation of GCMs, the Pakistan climate storylines were able to express uncertainty, allowing a range of adaptation actions to be considered. This top-down climate modeling is important in furnishing a snapshot of potential changes to climate over a range of timescales, but without the necessary bottom-up qualitative information about local levels of vulnerability, exposure and resilience (as shown in Figure 3), the climate data would not be sufficient to analyse risk and create effective adaptation strategies.

3.2.5. Assessment of risk

Before ICICLE storylines could be considered for the provinces of Pakistan, evidence of vulnerability, exposure and resilience was needed. As stakeholder input was limited, the EM-DAT database was accessed to provide information about the numbers and types of disasters recorded in different provinces over the last three decades (CRED/UCLouvain, 2022). Whilst this information helped to inform the description of the impact of the projected climate changes, a comprehensive literature review, including over three hundred different sources, provided information to link these physical effects with possible socio-economic outcomes. As disaster datasets must consider a global scope, data normally miss the resolution necessary to record the effects at community level, so the use of gray literature, including NGO reports and local newspaper interviews, is essential in gaining a better understanding of events (Mitheu et al., 2022).

In the absence of comprehensive stakeholder input, in Pakistan, a risk chart for each province was drawn up from data in the existing literature. This considered 11 disaster indices that were available from peer-reviewed papers and reports. The risk indices used were:

1. Drought hazard: Number affected by 2018 drought (in 1000s of people) (OCHA, 2018).
2. Heat hazard: Expected annual exposure to high heat stress (in 1000s of people) (World Bank Group, 2022).
3. Poverty headcount 2019/20 (% of population) (World Bank Group, 2022).
4. River flood hazard: Expected annual impact built-up damage (in hectares) (World Bank Group, 2022).
5. River flood hazard: Expected annual impact agricultural land damage (in hectares) (World Bank Group, 2022).

6. GLOF hazard based on data from National Disaster Management Authority (SEBCON Ltd, 2020).
7. Landslide hazard: Number of landslides and avalanches recorded for specific district from 1992 to 2022 (where only a province is given this is not included in the data) (CRED/UCLouvain, 2022).
8. Flash flood hazard: Number of flash floods recorded for specific district from 1992-2022 (where only a province is given this is not included in the data) (CRED/UCLouvain, 2022).
9. Riverine flood hazard: Number of riverine floods recorded for specific district from 1992-2022 (where only a province is given this is not included in the data) (CRED/UCLouvain, 2022).
10. Storm hazard: Number of severe storms recorded for specific district from 1992-2022 (where only a province is given this is not included in the data) (CRED/UCLouvain, 2022).
11. Population density (in people/km^2) (Mazhar, 2018; Pakistan Bureau of Statistics, 2022).

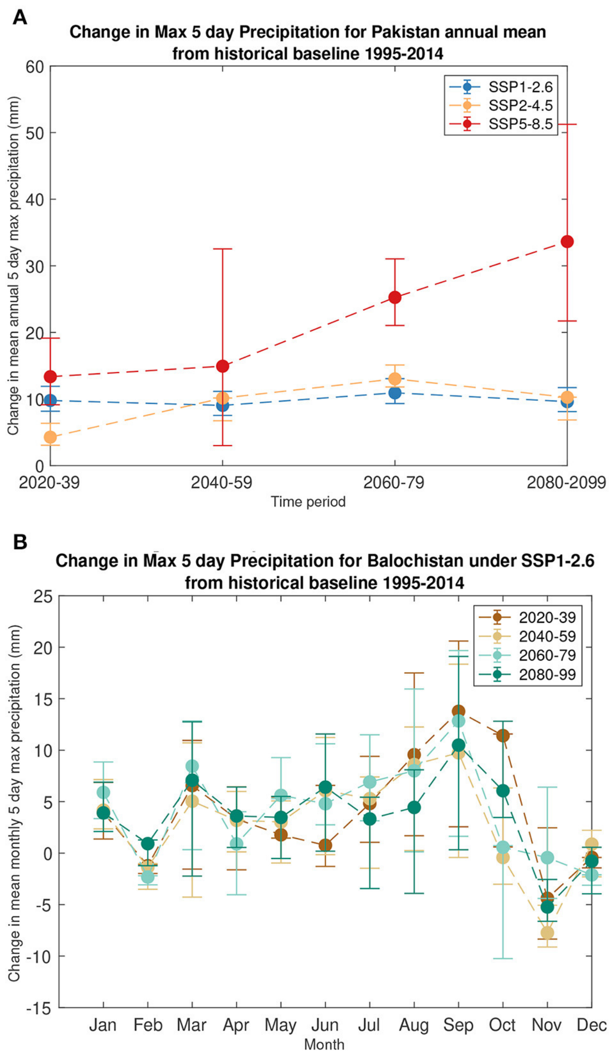

FIGURE 6
Graphs showing maximum 5 day rainfall information. **(A)** Time period changes for all of Pakistan. **(B)** Monthly variation for Balochistan.

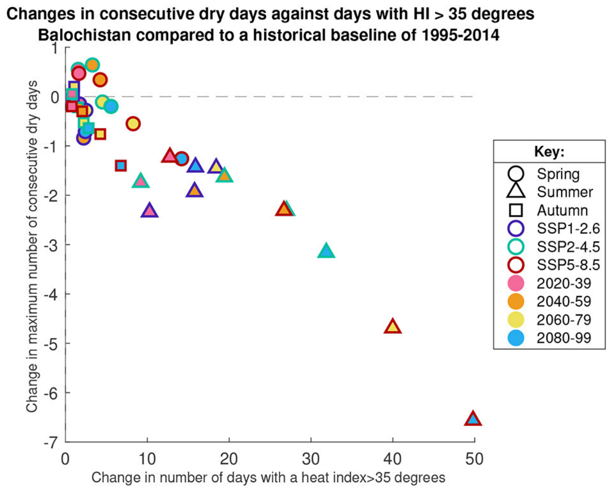

FIGURE 7
Link between number of days with a dangerous heat index and number of consecutive dry days for Balochistan.

Every district was given a rank for each disaster index or indicator, based on whether data put them in any of the top five deciles for that particular index. The chart provides a good understanding of not just which districts are most at risk from climate events, but also where there is vulnerability and exposure to specific hazards. This allows provincial teams to decide how to prioritize adaptation. Where data has been taken from grouped data sets there are many ties in the ranking, but with more local knowledge, actual figures could be used allowing a finer discretization of priorities. With scope for more detailed analysis in future iterations of the process, scientific impact analysis such as hydrological modeling could also be undertaken. The datasets chosen reflect the key priorities in adapting to increase resilience and reduce vulnerability and exposure, but these are not an exhaustive set and discussion with stakeholders will allow particular provincial information to be included as necessary. In Figure 8 part of the table for the province of Sindh is shown as an example. From this Badin District can be picked out as an area where adaptation to protect those with least resources from heat and drought would be most fitting, whilst Karachi is at risk from floods of all kinds which are made more devastating by the sheer density of the population, so measures to reduce exposure via infrastructure projects would be best here. Before any major infrastructure changes were actioned, more studies would be needed, but at this first iteration initial, smaller-scale adaptation measures, as well as the focus for future analysis in each district, could be instigated.

3.2.6. Development of ICICLE storylines

As has been explained in Section 2, one of the main advantages of using ICICLE storylines in planning adaptation lies in incorporating uncertainty within a projected future in a way that is accessible to broad audiences. In this way actions benefiting communities under a range of scenarios can be co-planned. In the case of Pakistan, a comprehensive review of

District	1: Drought (1000s)	2: Heat (100s)	3: Poverty (% of population)	4: River flood: Built-up (hectares)	5: River flood: Agriculture (hectares)	7: Landslide (31-year total)	8: Flash flood (31-year total)	9: Riverine Flood (31-year total)	10: Storm (31-year total)	11: Population density (people/km^2)
Badin	200-700	350-700	39-52	2.5-10	50-100			2	1	268
Dadu	200-700	350-700	26-39	2.5-10	100-200		1	6		81
Ghotki		350-700	26-39	17-35	100-200			4		270
Hyderabad		350-700	0-13	>35	20-50	1		3	2	398
Jacobabad		200-350	26-39	17-35	100-200			4		191
Jamshoro	200-700	200-350	26-39	2.5-10	20-50					88
Karachi		>700	0-13	0.1-2.5	<5	1	2	8	2	2795
Kashmore		200-350	13-26	>35	100-200					420
Khaipur		350-700	26-39	2.5-10	50-100			3		151
Larkana		350-700	13-26	10-17	50-100			4		205
Matiari		200-350	26-39	>35	50-100					543
Mirpur Khas		350-700	26-39	10-17	50-100			2		515
Naushamro Feroze		350-700	26-39	2.5-10	20-50			2		548

Top 10%
20%
30%
40%
50%

FIGURE 8
An excerpt from the risk chart compiled for all districts of the province of Sindh in Pakistan. More details about each risk category can be found in Section 3.2.5.

available literature and discussion with sectoral experts from the Walker Institute allowed socio-economic effects of likely climate impacts in each province of Pakistan to be described. Where local stakeholder information was available, this was fed into the process. However, in future iterations of ICECCAP it is hoped that this is a more comprehensive part of the creation of ICICLE storylines. An example of a climate storyline and the associated socio-economic implications, making up an ICICLE storyline, is given in Figure 9. With more stakeholder involvement, these ideas could be fine tuned and a more locally nuanced picture of potential socio-economic impacts created. Equally the robustness of the local picture would be further increased by judicious use of complex hydro-met and agricultural models, as has been suggested for later iterations of the project.

Infographics showing ICICLE storylines for Pakistan only included one future scenario, due to the scope of the project brief. However, ICICLE storylines by nature do incorporate uncertainty. Rather than giving a quantified measure of the accuracy of predictions, which can lead to inaction where uncertainties seem large, ICICLE storylines allow decisions to be made based on plausible futures. In saying that temperatures will rise, but not

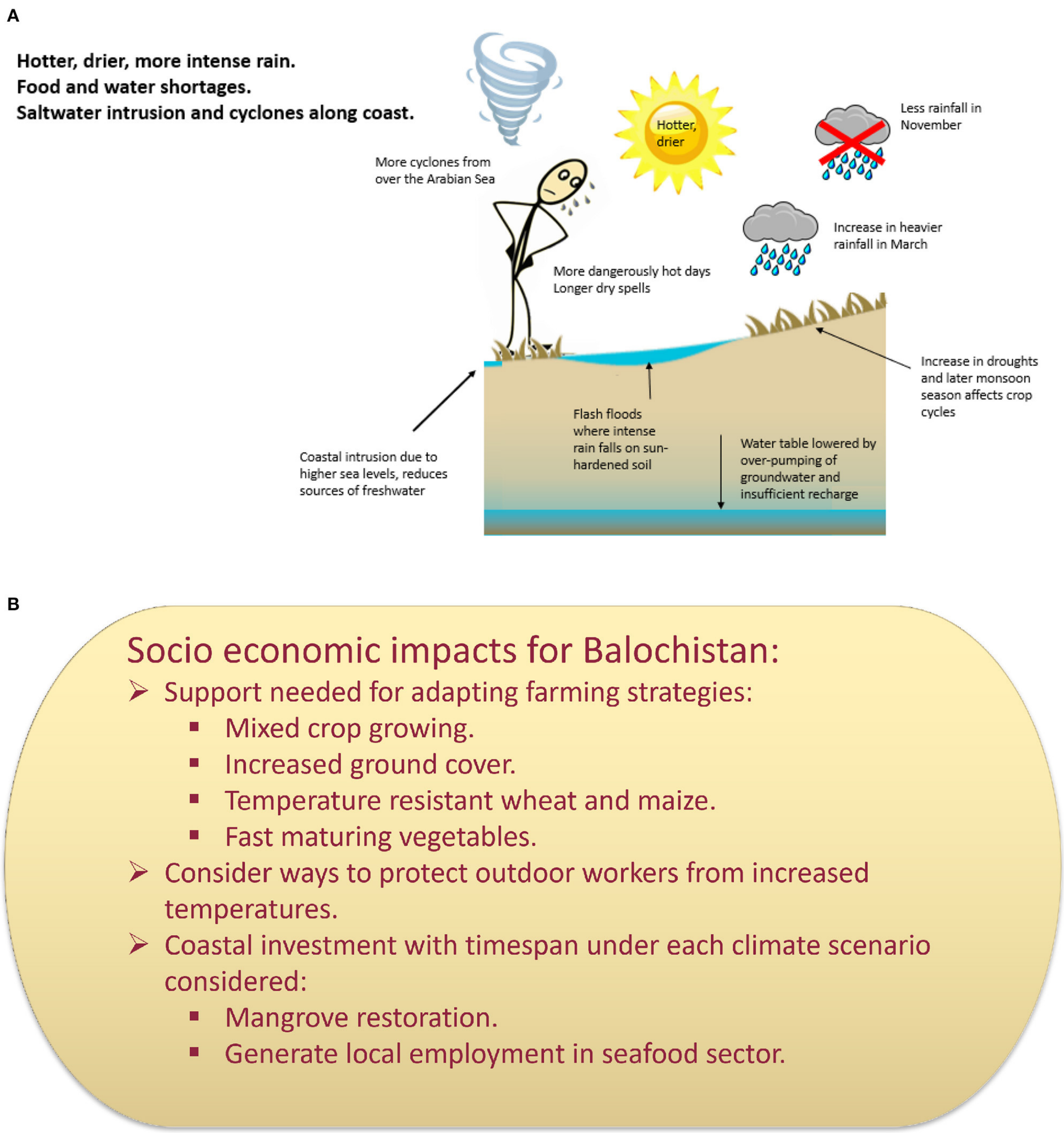

FIGURE 9
ICICLE storyline for Balochistan. **(A)** Infographic. **(B)** Extended socio-economic effects and adaptation options from expert judgement.

claiming to quantify this to the nearest degree, adaptation planning can be started. As the more complex and localized models are incorporated into the process, then a range of ICICLE storylines would be required to give a more comprehensive picture of different scenarios. In Pakistan, the climate projection conclusions drawn were sufficiently robust to aid adaptation planning, but a key part of the enabling environment was to suggest incorporating locally down-scaled information at the next iteration and allow for more ICICLE storylines to be considered.

3.2.7. Workshop discussing adaptation options

With much of the analysis on this first cycle completed, the most effective way to start piecing together "no regrets" adaptation options and to review the enabling environment hexagons, is to gather a broad group of stakeholders with expertise in many fields for a consultation workshop. This not only enhances capacity, via a full description of the process up to this point, but also ensures that stakeholders are ready to start implementing adaptation actions, given that they have agreed on what the barriers to this process could be and how these can be overcome, including ensuring that all relevant resources are in place. In practice implementation of large scale projects may only happen after a further phase of research and modeling at a finer scale, which has been identified as necessary through the use of the enabling environment. However, the ICECCAP allows identification of immediately actionable adaptation strategies, so that these can be started whilst the next iteration is underway.

Unfortunately a final workshop in Pakistan has not yet been scheduled and so far the Pakistan project has had a limited final audience. However, it is hoped that by following ICECCAP in future, representatives from each province can access and add to the research. By reviewing literature and listening to the limited stakeholder input we received, enabling environment diagrams evolved during the process, describing barriers to adaptation and what support would be needed to remove these. An example of these completed charts is given in Figure 10. In the case of Pakistan's water resources governance is a very important part of the enabling environment, as many of the issues that Pakistan is having to deal with can be solved by stricter water and pollution management and longer term action planning to take into account both the threat of floods and droughts. In the blue section of Figure 10 one important example of missing data is the monitoring of river flow rates. This is key not only to looking at fluctuations in flow due to climate events, but also to checking what extraction levels are and whether enough environmental flow is reaching the Indus Delta to prevent further saltwater intrusion upstream. The cyan triangle gives details on what research or scientific understanding is still needed to underpin adaptation plans, which in Pakistan was shown to include prediction of stream-flow based on weather indices. Capacity building required, shown in the yellow section of the hexagon, highlights the need for people to understand the dangers of overusing groundwater. The magenta section of the diagram shows how adaptation can be funded and what changes are needed to current financial structures. For example, no-one in Pakistan is likely to stop groundwater pumping and instead try to harvest rainwater, all the time pumping is heavily subsidized, but there is no financial incentive to store water when it is plentiful. The final section (shown in pale pink) lists some of the resources that will need to be put in place to enable adaptation, such as improved maintenance of the canal system and urban drainage systems, which are top priorities for Pakistan's water resource management.

The final workshop of the cycle, during which findings can be shared, is an essential part of ICECCAP. It can be used to provide useful validation for the completed report as well as enabling input into adaptation planning and barrier removal, based on the ICICLE storylines. However, its most important purpose lies in agreeing on how the next iteration of the process can be undertaken, whilst initial adaptation measures are already being implemented, so that the process is seen as a continuous cycle of constant updating and improvement, without risking delay to adaptation actions that can be undertaken immediately.

4. Discussion

Under climate change, risks can result from both impacts and human responses to them, so it is imperative that any evaluation of risk leads to the right adaptation actions (Reisinger et al., 2020). In this way adverse effects on all aspects of human life, ecosystems and infrastructure can be minimized. ICECCAP, as outlined in Section 2, has been effective in Pakistan, despite the limited project scope and reduced level of stakeholder engagement, but could be still more powerful when applied iteratively over time. This is very much just the first application of this process, but is there really a need for a new approach to supporting National Adaptation Planning?

Unfortunately with no standard type of assessment in place and no precise definition of vulnerability, all too often risk assessment methods are unable to bridge the gap between climate science and adaptation policy implementation (Shepherd, 2021; Simpson et al., 2021; Arribas et al., 2022; Olivares-Aguilar et al., 2022). Arribas et al. (2022) assert that CCRA methods are in need of an immediate overhaul, with the four key priorities identified in this research being better use of geospatial data and treatment of uncertainties, the development of a standard method to allow for comparison of results between different locations, stakeholder involvement via participatory governance and greater transparency in terms of evaluating effectiveness of interventions made as a result of new CCRA techniques. ICECCAP has concentrated on providing a universal CCRA methodology, which incorporates uncertainty in a positive way and champions stakeholder engagement. Crucially, we have also provided an enabling environment framework, to aid implementation, so that findings can be acted upon.

Another important innovation to tackle the previous issues with CCRA and the adaptation paralysis often documented in research, comes from using a combination of top-down and bottom-up analysis. Parallel use of these tools is advocated by the WCRP My Climate Risk Lighthouse Activity network (Blair et al., 2022; Cao et al., 2022). Striking a balance between such approaches does not mean ignoring available global and regional models, satellite information and reanalysis data, but using these in tandem with local data and most importantly, contextual socio-economic information on vulnerability, exposure and resilience (Cao et al., 2022). For established climate science institutions, one of the key changes will be learning to listen to community experts and local level stakeholders, so that information provided can be used by all, immediately (Blair et al., 2022). By incorporating all the relevant information strands, using an interdisciplinary strategy, specific impacts likely to be encountered in particular communities can be assessed, making adaptation choices much more pertinent and effective.

Too often quantified uncertainty of climate effects acts as a barrier to action, but by applying the method of ICICLE storylines the uncertainty in assessing risk changes from a negative to a positive factor, ensuring that all plausible futures are considered (Reisinger et al., 2020). Decision-making under uncertainty is fraught with difficulties, climate uncertainties are not the only sources of potential error, but understanding the importance of context will help to reduce generalization and lead to what the My Climate Risk network call managing climate risk "as if people mattered" (Cao et al., 2022).

The only way to change from incremental adaptation methods, that make slow steady changes, to a fully transformational approach, that keeps pace with alterations in the climate, is to remove the soft barriers that limit the efficacy of proposed

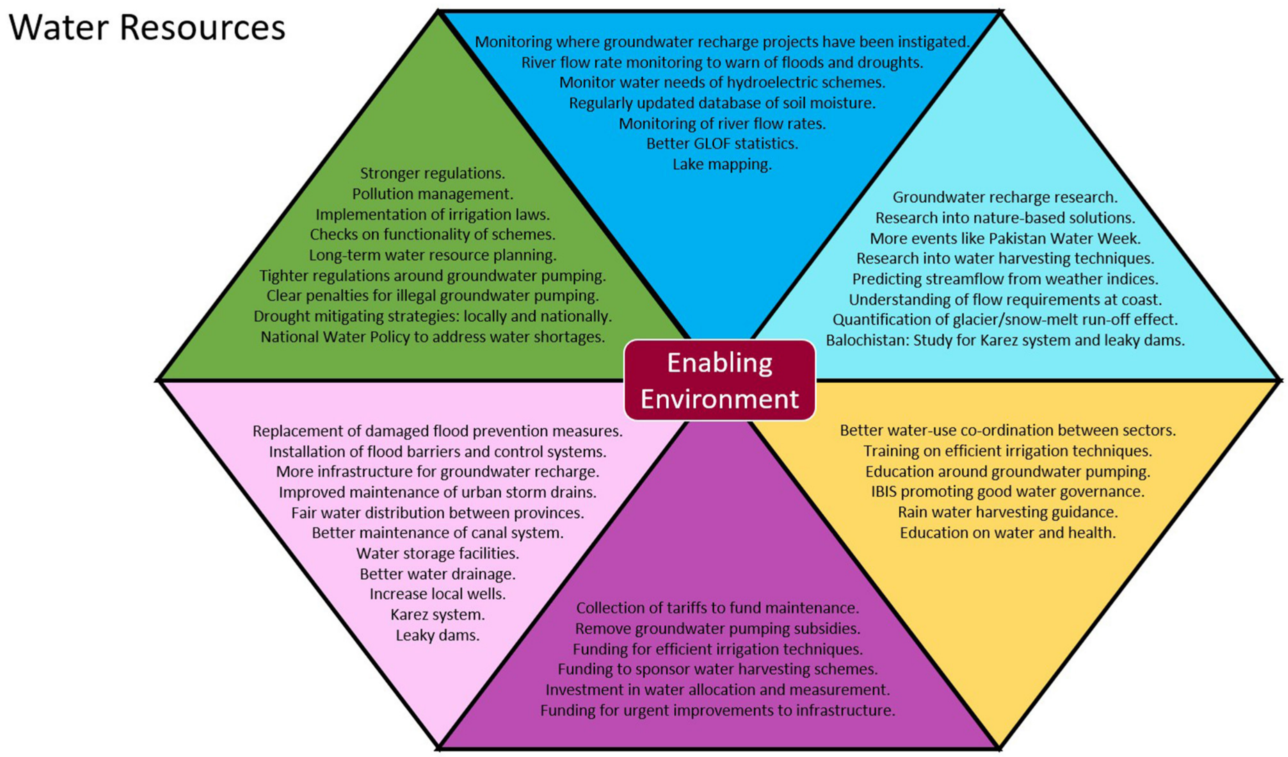

FIGURE 10
Enabling Environment for water resources in Pakistan.

actions (Portner et al., 2022). We believe that ICECCAP does just that, thus answering calls for a new approach to CCRA and adaptation planning.

In advocating this approach it is important to note that ICECCAP is an iterative process. Ideally all resources would be available to produce a fully comprehensive set of ICICLE storylines incorporating all plausible climate futures from the outset, but actually, the process is designed to be evolving, so that the adaptation measures deemed possible and useful at the end of the first phase can be started whilst more detailed research is taking place in the second iteration. This means that further adaptation can be planned at the end of each cycle without delaying the start of implementing already identified no regrets strategies.

A large emphasis in ICECCAP is placed on having extensive, cross-level and iterative stakeholder engagement. This is certainly advisable, but in practice not always possible. The research in Pakistan was limited by having access to the views of only a few high level experts, but by using gray literature and previously published research that made use of stakeholder surveys, we were able to piece together a more comprehensive view. The main lesson to be drawn from the difficulties in Pakistan is the importance of having an in-country contact or project team presence to make stakeholder engagement more personal and thus improve participation.

5. Conclusions

This research answers recent calls for an overhaul to CCRA, as ICECCAP gives a structured, consistent method for considering all types of risk in supporting adaptation planning at a national, regional and local level in a manner that can be methodically compared and implemented. Incorporating climate projections, details of previous climate impacts and current measures of vulnerability, exposure and resilience into ICICLE storylines and producing an associated infographic, allows stakeholders from diverse backgrounds to access the information easily and directly. This facilitates discussion of the implications of such climate changes to adaptation planning. Enabling environment diagrams are compiled throughout this process, based on the missing laws, data, science, capacity, funding, and resources that are identified as underpinning action to reduce the potential impact of future events. This means that as barriers are overcome, the next iterations of ICECCAP can become more detailed in the level of data and research available and those in-country better supported to continue the process.

By using the initial case study from Pakistan it has been shown that ICECCAP can be applied even with a limited level of access to stakeholder information. It can be completed at different resolutions and with the scope for more or less associated research. Most importantly, ICECCAP requires a synergy of top-down quantitative climate analysis and bottom-up socio-economic quantitative and qualitative information, in line with the My Climate Risk approach. In all cases stakeholder engagement is vital in providing the most current information and the most nuanced views, whilst also encouraging participation in the implementation of chosen policies in the future. So although the research completed to support the Pakistan NAP was valuable, it is hoped that future projects undertaken can be still more inclusive and reach a wider audience, enabling more immediate action. A key part of he Pakistan project was to explain how the process can be applied, so that in future a full cross-sectoral and all province ICECCAP is undertaken.

Creating ICICLE storylines and enabling environments based on our method will allow stakeholders to engage not just with the process, but also with each other, ensuring a cross-sectoral approach to adaptation planning. This is particularly important as it has been shown that where there is a lack of communication between stakeholders, this can lead to a less joined-up approach, leaving adaptation policies lacking a sufficient foundation of information and knowledge (Lee et al., 2022). Although in the case study an interdisciplinary research group from the Walker Institute at the University of Reading led the ICECCAP, the method as set out in the paper can be used by climate product and service developers, NGOs and local climate modeling units and Climate Change Ministries, as well as academics.

In the future it is hoped that ICECCAP can be applied to other regions. It is also expected that domestic capacity will be built in Pakistan, to allow continuing iterations of ICECCAP. As more regions are able to use this process it will be important to monitor and evaluate the effectiveness of actions taken. In this way we can ensure that the gap between policy and implementation in climate adaptation is bridged, so that "concerted global action is no longer delayed" (Portner et al., 2022).

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

CW, ES, RC, and CP contributed to conception and design of the study. CW performed statistical analysis, led research for the Pakistan case study, and wrote the first draft of the manuscript. CP contributed livelihoods analysis to the case study. CP, ES, and RC wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

Funding

Research funded through the Walker Institute at the University of Reading.

Acknowledgments

The case study is based on a consortium project. We would like to thank our consortium colleagues from WSP Global Inc., Olga Buto, and Christine Wissink for their contributions to the case study highlighted. We would also like to thank Jessica Troni of UNEP and the UNEP Pakistan team for reviewing and contributing to the original Pakistan report from which the case study used in this paper is drawn.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Akbar, S., Nazir, A., Ali Shah, S., Hadayat, A., and Almohammad, H. (2022). Urban flooding assessment due to climate change during monsoon season: a case study in Islamabad and Rawalpindi. *Ecofeminism Clim. Change* 3, 85–88. doi: 10.26480/efcc.02.2022.85.88

Ali, A., and Erenstein, O. (2017). Assessing farmer use of climate change adaptation practices and impacts on food security and poverty in Pakistan. *Clim. Risk Manage.* 16, 183–194. doi: 10.1016/j.crm.2016.12.001

Ali, S., Eum, H., Jaepil, C., Li, D., Khan, F., Dairaku, K., et al. (2019). Assessment of climate extremes in future projections downscaled by multiple statistical downscaling methods over Pakistan. *Atmos. Res.* 224, 1–196. doi: 10.1016/j.atmosres.2019.03.030

Ali, S., Saeed, A., Kiani, R., Goheer, M., Muhammad, S., Khan, F., et al. (2021). Future climatic changes, extreme events, related uncertainties, and policy recommendations in the Hindu Kush sub-regions of Pakistan. *Theoret. Appl. Climatol.* 143, 193–209. doi: 10.1007/s00704-020-03399-7

Amin, M., Bano, D., Hassan, S., Goheer, M., Khan, A., Khan, M., et al. (2020). Mapping and monitoring of glacier lake outburst floods using geospatial modelling approach for Darkut Valley, Pakistan. *Meteorol. Appl.* 27, 1–12. doi: 10.1002/met.1877

Arribas, A., Fairgrieve, R., Dhu, T., Bell, J., Cornforth, R., Gooley, G., et al. (2022). Climate risk assessment needs urgent improvement. *Nat. Commun.* 13, 4326. doi: 10.1038/s41467-022-31979-w

Aven, T., and Renn, O. (2015). An evaluation of the treatment of risk and uncertainties in the IPCC reports on climate change. *Risk Anal.* 35, 701–712. doi: 10.1111/risa.12298

Azour, J., and Duenwald, C. (2022). *These Are the Countries Most at Risk From Climate Change, IMF reports*. Available online at: https://www.weforum.org/agenda/2022/04/climate-adaptation-middle-east-central-asia/ (accessed January 27, 2023).

Barde, V., Malasala, M., Mohanty, U., and Panda, R. (2023). Performance of the CORDEX-SA regional climate models in simulating summer monsoon rainfall and future projections over East India. *Pure Appl. Geophys*. 180, 1121–1142. doi: 10.1007/s00024-022-03225-3

Bellon, M., and Massetti, E. (2022). *Planning and Mainstreaming Adaptation to Climate Change in Fiscal Policy*. Technical report, Washington, DC: International Monetary Fund.

Bercht, A. (2021). How qualitative approaches matter in climate and ocean change research: uncovering contradictions about climate concern. *Glob. Environ. Change* 70, 102326. doi: 10.1016/j.gloenvcha.2021.102326

Bhave, A., Conway, D., Dessai, S., and Stainforth, D. (2016). Barriers and opportunities for robust decision making approaches to support climate change adaptation in the developing world. *Clim. Risk Manage.* 14, 1–10. doi: 10.1016/j.crm.2016.09.004

Blair, T., Shepherd, T., Rodrigues, R., and van der Wel, N. (2022). *My Climate Risk: General Assembly*. Technical report, Geneva: World Climate Research Programme.

Bowcott, H., Fomenko, L., Hamilton, A., Krishnan, M., Mysore, M., Trittipo, A., et al. (2021). *Protecting People from a Changing Climate: The Case for Resilience*. Available online at: https://www.mckinsey.com/capabilities/sustainability/our-insights/protecting-people-from-a-changing-climate-the-case-for-resilience (accessed January 31, 2023).

Butt, A. (2022). *It's time for South Asia to Talk Climate*. Available online at: https://www.usip.org/publications/2022/10/its-time-south-asia-talk-climate (accessed January 27, 2023).

Cao, W., Rodrigues, R., Shepherd, T., and van der Wel, N. (2022). *My Climate Risk: General Assembly*. Technical report, Geneva: World Climate Research Programme.

Chapman, A., Davies, W. and Lang, Y. (2021). *Climate Risk Country Profile: Pakistan: The World Bank Group and the Asian Development Bank*. Technical report.

Conway, D. (2011). Adapting climate research for development in Africa. *WIREs Clim. Change* 2, 428–450. doi: 10.1002/wcc.115

Conway, D., Nicholls, R., Brown, S., Tebboth, M., Adger, W., Ahmad, B., et al. (2019). The need for bottom-up assessemnts of climate risks and adaptation in climate-sensitive regions. *Nat. Clim. Change* 9, 503–511. doi: 10.1038/s41558-019-0502-0

Cornforth, R., Petty, C., and Walker, G. (2020). "Supporting climate-resilient planning at national and district levels: a pathway to multi-stakeholder decision-making in Uganda," in *Climate Risk in Africa*, eds D. Conway and K. Vincent (Cham: Palgrave Macmillan; Springer Nature), 131–145.

Cornforth, R., Saggioro, E., Petty, C., Wilby, R., Pope, H., and Tarnavsky, E. (2022). *Climate Risk Assessments for Iraq: the Southern Marshes Eco-Region and Persian Gulf and Shatt Al-Arab Eco-Region*. Technical report, Reading: Walker Institute.

CRED/UCLouvain (2022). *The International Disaster Database:EM-DAT*. Available online at: www.emdat.be (accessed November 10, 2022).

Dezfuli, A., Razavi, S., and Zaitchik, B. (2022). Compound effects of climate change on future transboundary water issues in the Middle East. *Earths Future* 10, e2022EF002683. doi: 10.1029/2022EF002683

Dinerstein, E., Olson, D., Joshi, A., Vynne, C., Burgess, N., Wikramanayake, E., et al. (2017). A framework for multi-sensor satellite data to evaluate crop production losses: the case study of 2022 Pakistan floods. *Bioscience* 67, 534–545. doi: 10.1093/biosci/bix014

Dvorak, Z., Rehak, D., David, A., and Cekerevac, Z. (2020). Qualitative approach to environmental risk assessment in transport. *Int. J. Environ. Res. Public Health* 17, 5494. doi: 10.3390/ijerph17155494

ECCCDD (2021). *Sindh Climate Change Policy*. Technical report, Karachi.

EPA KP (2022). *Khyber Pakhtunkhwa Climate Action Plan*. Technical report, Peshawar.

Etana, D., Sneider, D., van Wesenbeeck, C., and de Cock Buning, T. (2021). The impact of adaptation to climate change and variability on the livelihood of smallholder farmers in Central Ethiopia. *Sustainability* 13, 6790. doi: 10.3390/su13126790

Ferris, E., and Weerasinghe, S. (2020). Promoting human security: Planned relocation as a protection tool in a time of climate change. *J. Migrat. Hum. Secur.* 8, 134–149. doi: 10.1177/2331502420909305

File, D., and Derbile, E. (2020). Sunshine, temperature and wind: Community risk assessment of climate change, indigenous knowledge and climate change adaptation planning in Ghana. *Int. J. Clim. Change Strat. Manage.* 12, 22–38. doi: 10.1108/IJCCSM-04-2019-0023

Fouqueray, T., and Frascaria-Lacoste, N. (2020). Social sciences have so much more to bring to climate studies in forest research: a French case study. *Ann. Forest Sci.* 77, 81. doi: 10.1007/s13595-020-00989-3

Fu, S., Chen, L., Woldai, T., Yin, K., Gui, L., Li, D., et al. (2020). Landslide hazard probability and risk assessment at the community level: a case of western Hubei, China. *Nat. Hazards Earth Syst. Sci.* 20, 581–601. doi: 10.5194/nhess-20-581-2020

Fullwood-Thomas, J., and Saqlain, A. (2017). *Enhancing the Evidence Base for Vulnerability and Risk Assessment in Badin, Pakistan*. Technical report, Kilimani: Oxfam.

Gogoi, E., Bahadur, A., and Rumbaitis del Rio, C. (2017). "Mainstreaming adaptation to climate change within governance systems in South Asia: an analytical framework and examples from practice," in *Action on Climate Today Learning Paper* (London).

Gornish, E., Hamilton, J., Barberan, A., Benito, B., Binzer, A., Demeester, J., et al. (2013). Interdisciplinary climate change collaborations are essential for early-career scientists. *EoS Trans. Am. Geophys. Union* 94, 151. doi: 10.1002/2013EO160003

Green Climate Fund (2022). *Readiness and Preparatory Support: Building Capacity to Advance National Adaptation Plan Process in Pakistan*. Technical report, Nairobi.

Haasnoot, M., Kwakkel, J., Walker, W., and ter Maat, J. (2013). Dynamic adaptive policy pathways: a method for crafting robust decisions for a deeply uncertain world. *Glob. Environ. Change* 23, 485–498. doi: 10.1016/j.gloenvcha.2012.12.006

Hafeez, E., and Fasih, T. (2018). Growing population of Pakistani youth: a ticking time bomb or a demographic dividend. *J. Educ. Educ. Dev.* 5, 211–226. doi: 10.22555/joeed.v5i2.2022

Hafeez, S. (2022). *Issue Brief on Rethinking the Policy Capacity of Pakistan to adopt Blue-Green Infrastructure*. Available online at: https://issi.org.pk/issue-brief-on-rethinking-the-policy-capacity-of-pakistan-to-adopt-blue-green-infrastructure/ (accessed January 27, 2023).

Hallegatte, S., Rentschler, J., and Rozenberg, J. (2020). *Adaptation Principles: A Guide for Designing Strategies for Climate Change Adaptation and Resilience*. Technical report, Washington, DC: World Bank.

Hassan, S., Ajmal, M., Khan, A., Goheer, M., Khattak, M., Ali, S., et al. (2019). Multi-criteria decision analysis for flood risk on the Chenab River. *R. Meteorol. Soc. Weather* 74, 65–75. doi: 10.1002/wea.3490

Hawchar, L., Naughton, O., Nolan, P., Stewart, M., and Ryan, P. (2020). A GIS-based framework for high-level climate change risk assessment of critical infrastructure. *Clim. Risk Manage.* 29, 100235. doi: 10.1016/j.crm.2020.100235

Hawkins, E., and Sutton, R. (2009). The potential to narrow uncertainty in regional climate predictions. *Bull. Am. Meteorol. Soc.* 90, 1095–1108. doi: 10.1175/2009BAMS2607.1

HMGovernment (2022). *UK Climate Change Risk Assessment 2022*. Technical report, London.

Human Rights Council (2020). *Analytical Study on the Promotion and Protection of the Rights of Persons With Disabilities in the Context of Climate Change*. Technical report, New York, NY.

Idris, I. (2021). *Areas and Population Groups in Pakistan Most Exposed to Combined Effects of Climate Change, Food Insecurity and COVID-19*. Technical report, Brighton: Institute of Development Studies.

Iqbal, M. (2020). Effect of climate change on health in pakistan. *Proc. Pak. Acad. Sci. B Life Environ. Sci.* 57, 1–12.

Isaczai, G. (2022). *Climate Change Is the Biggest Threat Iraq Has Ever Faced, But There Is Hope to Turn Things Around*. Available online at: https://iraq.un.org/en/207205-climate-change-biggest-threat-iraq-has-ever-faced-there-hope-turn-things-around (accessed Febraury 1, 2023).

Jack, C., Jones, R., Burgin, L., and Daron, J. (2020). Climate risk narratives: an iterative reflective process for co-producing and integrating climate knowledge. *Clim. Risk Manage.* 29, 100239. doi: 10.1016/j.crm.2020.100239

Jehangir, J. (2018). *Performance Audit Report on Mirani Dam Project*. Technical report, Islamabad: National Government of Pakistan.

Kapoor, A., Alcayna, T., de Boer, T., and Gleason, K. (2021). *Climate Change Impacts on Health and Livelihoods*. Technical report, The Hague: International Federation of Red Cross.

Lee, S., Paavola, J., and Dessai, S. (2022). Towards a deeper understanding of barriers to national climate change adaptation policy: a systematic review. *Clim. Risk Manage.* 35, 100414. doi: 10.1016/j.crm.2022.100414

Lemos, M., and Rood, R. (2010). Climate projections and their impact on policy and practice. *WIREs Clim. Change* 1, 670–682. doi: 10.1002/wcc.71

Marshall, G. (2014). *Don't Even Think About It: Why Our Brains Are Wired To Ignore Climate Change*. Manhattan: Bloomsbury.

Mayfield, H., Eberhard, R., Baker, C., Baresi, U., Bode, M., Coggan, A., et al. (2023). Designing an expert-led Bayesian network to understand interactions between policy instruments for adoption of eco-friendly farming practices. *Environ. Sci. Policy* 141, 11–22. doi: 10.1016/j.envsci.2022.12.017

Mazhar, F. (2018). Population distribution in sindh according to census 2017. *Int. J. Innovat. Sci. Res. Technol.* 3, 305–309.

Mbah, M., Shingruf, A., and Molthan-Hill, P. (2022). Policies and practices of climate change education in South Asia: towards a support framework for an impactful climate change adaptation. *Clim. Act.* 1, 28. doi: 10.1007/s44168-022-00028-z

Mimura, N., Pulwarty, R., Elshinnawy, I., Redsteer, M., Huang, H., Nkem, J., et al. (2014). "Adaptation planning and implementation," in *Climate Change 2014: Impacts, Adaptation and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, eds R. Moss and W. Vergara (Cambridge: Cambridge University Press), 869–898.

Mitheu, F., Petty, C., Tarnavsky, E., Stephens, E., Ciampi, L., Butsatsa, J., et al. (2022). Identifying the barriers and opportunities in the provision and use of weather and climate information for flood risk preparedness: the case of Katakwi District, Uganda. *Front. Clim.* 4, 908662. doi: 10.3389/fclim.2022.908662

MoCC (2021). *Punjab Provincial Climate Change Action Plan*. Technical report, Islamabad.

Nachmany, M., Byrnes, R., and Surminski, S. (2019). *National Laws and Policies on Climate Change Adaptation: A Global Review*. Centre for Climate Change Economics and Policy: Policy Brief.

New, M., Reckien, D., Viner, D., Adler, C., Cheong, S., Conde, C., et al. (2022). "Adaptation planning and implementation," in *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, eds R. Klein and Z. Zommers (Cambridge: Cambridge University Press), 2539–2654.

Niles, M., Ferdinand, T., Choularton, R., and Carter, R. (2020). *Opportunities for Crop Research, Development and Adoption to Drive Transformative Adaptation in Agriculture*. World Resources Institute Working Paper.

OCHA (2018). *Pakistan Drought Factsheet 20190523*. Available online at: https://www.humanitarianresponse.info (accessed November 23, 2022).

OCHA (2023). *reliefweb*. Available online at: https://www.https://www.unocha.org/ (accessed June 20, 2022).

OECD (2021). *Managing Climate Risks, Facing Up to Losses and Damages*. Technical report, Paris.

Olivares-Aguilar, I., Sanchez-Davila, G., Wildermann, N., Clark, D., Floerl, L., Villamizar, E., et al. (2022). Methodological approaches to assess climate vulnerability and cumulative impacts on coastal landscapes. *Front. Clim.* 4, 1018182. doi: 10.3389/fclim.2022.1018182

Pakistan Bureau of Statistics (2022). *Population Census 2017*. Available online at: https://www.pbs.gov.pk (accessed November 23, 2022).

Pakistan Ministry of Climate Change (2021). *National Climate Change Policy*. Technical report, Islamabad.

Parry, J. (2016). *Review of Current and Planned Adaptation Action in Pakistan*. Technical report, Ottawa, ON: London: CARIAA.

PDMA Punjab (2022). *Provincial Disaster Management Authority District Plan*. Available online at: https://pdma.gop.pk/district-plan (accessed January 4, 2023).

Petty, C., Ngoleka, S., Cornforth, R., Achiro, E., Acidri, J., Ainslie, A., et al. (2022). Adaptation planning: an integrated approach to understanding vulnerability in the Lake Victoria Basin. *Front. Clim.* 3, 782534. doi: 10.3389/fclim.2021.782534

Portner, H.-O., Roberts, D., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegria, A., et al. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Technical report, Cambridge, UK: IPCC.

Qamer, F., Abbas, S., Ahmad, B., Hussain, A., Salman, A., Muhammad, S., et al. (2023). A framework for multi-sensor satellite data to evaluate crop production losses: the case study of 2022 Pakistan floods. *Nat. Sci. Rep.* 13, 4240. doi: 10.1038/s41598-023-30347-y

Reisinger, A., Howden, M., and Vera, C. E. A. (2020). *The concept of Risk in the IPCC Sixth Assessment Report: A Summary of Cross-Working Group Discussions*. Technical report, Geneva: IPCC.

Sapienza Consulting (2022). *Assessing and Diminishing Risks With Risk Likelihood*. Available online at: https://https://www.eclipsesuite.com/risk-likelihood/ (accessed February 1, 2023).

SEBCON Ltd (2020). *Stakeholders' Needs and Capacity Assessment at Federal, Provincial, District and Community Levels*. Technical report, Islamabad.

Shaw, R., Luo, Y., Cheong, T., Abdul Halim, S., Chaturvedi, S., Hashizume, M., et al. (2022). "2022: Asia," in *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (Cambridge, UK: IPCC).

Shepherd, T., and Lloyd, E. (2021). Meaningful climate science. *Clim.Change* 169, 17. doi: 10.1007/s10584-021-03246-2

Shepherd, T., Boyd, E., Calel, R., Chapman, S., Dessai, S., Dima-West, I., et al. (2018). Storylines: an alternative approach to representing uncertainty in physical aspects of climate change. *Clim. Change* 151, 555–571. doi: 10.1007/s10584-018-2317-9

Sillmann, J., Shepherd, T., van den Hurk, B., Hazeleger, W., Martius, O., Slingo, J., et al. (2021). Event-based storylines to address climate risk. *Earths Future* 9, e2020EF001783. doi: 10.1029/2020EF001783

Simpson, N., Mach, K., Constable, A., Hess, J., Hogarth, R., Howden, M., et al. (2021). A framework for complex climate change risk assessment. *One Earth* 4, 489–501. doi: 10.1016/j.oneear.2021.03.005

Taylor, A., Siame, G., and Mwalukanga, B. (2020). "Integrating climate risks into strategic urban planning in Lusaka, Zambia," in *Climate Risk in Africa*, eds D. Conway and K. Vincent (Cham: Springer Nature; Palgrave Macmillan), 115–129.

UN Office of the High Commissioner for Human Rights (2020). *Analytical Study on the Promotion and Protection of the Rights of Persons With Disabilities in the Context of Climate Change*. Technical report, Geneva.

UNFCCC (2021). *Adaptation and Resilience*. Available online at: https://unfccc.int/topics/adaptation-and-resilience/the-big-picture/introduction (accessed January 31, 2023).

UNHCR (2021). *Climate Change and Disaster Displacement*. Available online at: https://www.unhcr.org/uk/climate-change-and-disasters.html (accessed January 30, 2023).

United Nations Environment Programme (2021). *Adaptation Gap Report 2021: The Gathering Storm- Adapting to Climate Change in a Post-Pandemic World*. Technical report, Nairobi.

van den Hurk, B., Siegmund, P., Klein Tank, A., Attema, J., Bakker, A., Beersma, J., et al. (2014). *KNMI'14: Climate Change Scenarios for the 21st Century- A Netherlands Perspective*. Technical report, De Bilt: Royal Netherlands Meteorological Institute.

Waseem, M., Khurshid, T., Abbas, A., Ahmad, I., and Javed, Z. (2022). Impact of meteorological drought on agriculture production at different scales in Punjab, Pakistan. *J. Water Clim. Change* 13, 113–124. doi: 10.2166/wcc.2021.244

Water Resources Development Sector (2017). *Climate Risk and Vulnerability Analysis Report*. Technical report, Quetta.

WCRP (2023). *My Climate Risk*. Available online at: https://www.wcrp-climate.org/my-climate-risk (accessed March 18, 2023).

Weaver, C., Lempert, R., Brown, C., Hall, J., Revell, D., and Sarewitz, D. (2013). Improving the contribution of climate model information to decision making: the value and demands of robust decision frameworks. *WIREs Clim. Change* 4, 39–60. doi: 10.1002/wcc.202

Wells, C., Petty, C., Saggioro, E., and Cornforth, R. (2023). Pakistan climate change impact storylines based on existing vulnerability literature (version 5). *Zenodo*. doi: 10.5281/zenodo.8359361

Wilby, R., and Dessai, S. (2010). Robust adaptation to climate change. *Weather* 65, 180–185. doi: 10.1002/wea.543

Wilby, R., Lu, X., and Rodgers, C. (2018). *Information Sources to Support ADB Climate Risk Assessments and Management*. Technical report, Manila: Asian Development Bank.

Wilby, R., Troni, J., Biot, Y., Tedd, L., Hewitson, B., Smith, D., et al. (2009). A review of climate risk information for adaptation and development planning. *Int. J. Climatol.* 29, 1193–1215. doi: 10.1002/joc.1839

World Bank Group (2021). *Climate Change Knowledge Portal*. Available online at: https://climateknowledgeportal.worldbank.org/download-data (accessed November 10, 2022).

World Bank Group (2022). *Country Climate and Development Report*. Technical report, Washington, DC.

Young, H., Shepherd, T., Acidri, J., Cornforth, R., Petty, C., Seaman, J., et al. (2021). Storylines for decision-making: climate and food security in Namibia. *Clim. Dev.* 13, 515–528. doi: 10.1080/17565529.2020.1808438