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# Risk categorization and decision prioritization for climate change impacts: A rapid risk assessment methodology applied in the State of Qatar

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ABSTRACT

The impacts of climate change vary by location and severity, will be experienced over a range of timescales, and governments are not equally able to respond to risks and hazards in the same way. Yet, despite the rapid expansion of climate-related evidence, few studies categorize risks and hazards to support better-informed decision-making regarding the prioritization of action and investment. This paper develops a risk categorization tool and decision support heuristic, applied to the specific challenges faced in the Gulf Cooperation Council (GCC) region, and specifically in the State of Qatar. Drawing on expert assessment, the results of this study allow decision-makers to compare risks and hazards when making decisions about resource allocation and policy interventions. The results represent a localized categorization of climate risks and a comparative assessment based on three criteria. Standardized global assessments were used to validate the results. While the application of this study is specific to one country, the methodology and assessment approach could be applied in other contexts to enable more evidence-informed decision-making.

## Introduction

Climate change is a global challenge that has unique and varied local impacts. Some of the climate change risks facing the Gulf Cooperation Council (GCC) member states pose particular challenges that require adaptation and resilience responses that are tailored accordingly. These risks and hazards will have impacts not only on human health and biodiversity (terrestrial and marine; e.g., Conkey et al., 2023) but also on the economy (Al-Mohannadi and Al-Mohannadi, 2023; Wright, 2023) as increasing demands for cooling will place more demands for energy (Eveloy and Ayou, 2019), which at present increases hydrocarbon utilization. Similar pressures exist for the water supply, which is primarily obtained via energy-intensive desalination processes (Lawler et al., 2023), putting pressure on an already water-scarce region. The impact of sea level rise (and associated impacts, such as storm surges, extreme swale waves, salination of underground water sources, and coastal flooding) is of critical importance as many of the major cities in the GCC are low-lying coastal cities (Lambert and D'Alessandro, 2023). Increasing population, rapid economic development and an emphasis on maintaining generally high levels of human development (Pal et al., 2023) make these interconnected challenges particularly complex. Due to some geographic traits of the region (being arid and semi-arid) as well as being a region processing hydrocarbons, air quality is low and has the potential to worsen.

Climate change mitigation and adaptation within the GCC region requires substantive and multi-sectoral responses. For decision-makers, however, the evidence does not always lend itself toward supporting prioritized action and investment. For example, recent contributions to advancing localized knowledge on climate change impacts for Qatar have produced lists of recommendations (Cochrane and Al-Hababi, 2023b; Pal et al., 2023). Given that governments have limitations of resources and capacity, prioritization is required. To respond effectively, decision-makers need input on the severity of localized risks and hazards, their timescale of impacts, and the ability of the government to respond to them. This information enables prioritization and, therefore, appropriate resource allocation. Yet, studies of this sort are not common for the region; to our knowledge, no such study has been conducted on Qatar that provides this evidence. The rationale of this project and the aim of our study is to address this critical gap. The objectives of the study, therefore, are (a) identyfing climate risks that are specific to the State of Qatar and (b) categorizing them based on identified criteria. To do this, we survey subject matter experts to make these assessments and

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present heuristics to categorize risks and hazards. This approach does not necessarily suggest that near-term risks require greater attention than long-term ones, for example. What these heuristics offer are categorizations for better-informed decision-making, which is described in the methodology section, both in surveying experts and the utilization of heuristics. Before moving to the results of this study, we survey the existing evidence in global context as well as for the country study of the State of Qatar. The findings present different analyses of the results, for which we provide descriptive and analytical interpretation before concluding with key takeaway lessons.

## Methodology

This research provides a climate change risk assessment for Qatar considering two constraints. First, there is relatively little available research on the climate risks and hazards, in comparison to other countries. The IPCC Sixth Assessment Report highlights that regional- and national-level evidence is low for the whole West Asia region (2022, p. 1520). This paper uses a systematic literature review approach to synthesize what is available and utilize that evidence base to create a list of climate risks and hazards. Second, while one could study all of the issues in detail to provide for in-depth social, environmental, political, and economic costs, decision-makers do not have the luxury of that time to make decisions. This study draws on expert assessment to categorize and prioritize risks and hazards to support decision-making. This assessment begins by collecting evidence on climate change impacts, identifying a list of national-level risks, identifying criteria to assess them, and prioritizing and categorizing them based on experts' survey to contribute to better-informed climate change adaptation policies. Accordingly, the methodology consists of (a) conducting a systematic literature review, (b) establishing a climate risks list, (c) establishing assessment criteria, (d) developing a simple ranking survey, and (e) categorization and prioritization of 'national' risks based on identified criteria and the survey results.

The systematic literature review followed PRISMA protocol, with clear inclusion and exclusion criteria (see Table 1). The PRISMA protocol is commonly used for systematic reviews to describe the rationale and methods of the literature search, outlining clear and transparent parameters for inclusion and exclusion. In implementing the protocol, a data set was established that included all of the literature that met the inclusion criteria. The systematic literature review involved 41 papers on climate change in Qatar (journal articles, conference papers, and book chapters) published between the years 2006 and 2022. A synthesis of that literature is presented in the section that follows the Methodology.

**Table 1**
Criteria for inclusion and exclusion in systematic literature review.

| Criteria | Inclusion | Exclusion |
|---|---|---|
| Publication date | All publications (journal articles and book chapters) released as of October 2022 | Publications released after October 2022 |
| Key topic/theme of publication | Publications focusing on examining or projecting climate change impacts on Qatar whether in past, present, and future | Publications that do not contain any content on climate change impacts on Qatar |
| Publication Range | Publications focusing on Qatar | Publications focusing on other countries |
| Publication availability | Available in Scopus | Not available in Scopus |
| Type of publication | Peer-reviewed publications | Grey literature |
| Language of publication | English | Non-English |

Source: based on Song and Lee (2022).

Utilizing the available evidence (including IPCC assessment reports of 2014 and 2022 (IPCC, 2014)) as well as a recently published edited book on Qatar and sustainability issues (Cochrane and Al-Hababi, 2023b), a list of 15 climate risks and hazards was developed, for the development of the expert survey. For the purpose of providing an inclusive, comprehensive assessment, the list combines climate-related risks that are referred to or categorized in literature as climate impact, risks, and hazards. Additionally, to ensure the comprehensiveness of the survey, participants were asked to add climate risks or hazards that they think should be included. This research project surveyed experts in academic, government, and non-governmental roles in Qatar. Participants were invited based on their expert knowledge and positionality. Invited experts included scholars based at higher educational institutions that have published climate risks and/or hazards (Hamad Bin Khalifa University, Qatar University, the Doha Institute for Graduate Studies, Texas A&M University at Qatar, Georgetown University in Qatar, Qatar Environment & Energy Research Institute), practitioners employed at non-governmental institutions working on climate risks and/or hazards (Qatar Foundation, Doha Environmental Actions Project, Arab Youth Climate Movement Qatar, Earthna, Qatar Shell Research and Technology Centre, Gulf Organisation for Research & Development) and experts at governmental institutions employed to support decision-making regarding climate risks and/or hazards (Ministry of Environment and Climate Change, Ministry of Municipality, Kahramaa, Qatar National Food Security Programme). Although the sample size is small, the objective was to obtain expert opinion, rather than public perception.

Participants were asked to assess risks based on their expert judgement, according to severity, degree of control, and timescale. This approach allows strategic decision-making to be evidence-based (Eisenhardt and Zbaracki, 1992; Elbanna, 2006). Using the results of the expert input, we analysed the risks and hazards using decision support heuristics and risk categorization tools (Fig. 1) to enable evidence-based decision-making (including efficient and appropriate response and resource allocation; Krabuanrat and Phelps, 1998; Mousavi and Gigerenzer, 2014). Similar tools have been developed for other contexts; this application advances climate risk and response knowledge specific to Qatar and the GCC Region and climate risk policy amidst high levels of uncertainty and/or competing claims on prioritization. The risk survey and response analysis for Qatar presents a specific case study for how other countries in the Gulf Region can apply a similar approach to strengthen decision-making processes amidst the climate crisis.

The measurement framework developed for this study is a simple ranking survey tool that assesses climate risks according to three factors: severity, timescale, and ability to respond. For each scale, a common list of climate risks is provided (experts were given the opportunity to suggest others, but included: temperature increase on human health, systems risks related to heat stress, sea level rise, extreme weather events, terrestrial biodiversity loss, marine biodiversity loss, global economic risks, regional conflict risks, domestic economic risks (including impacts on hydrocarbon markets), impacts on global food supply, political risks in response to climate change, freshwater shortages, insufficient domestic governance capacity or response, unprepared domestic private sector for future markets). We applied for IRB in 2022 and were granted approval to conduct this study by Hamad Bin Khalifa University. The institution of the lead author holds a subscription to the Microsoft software package, and given the simplicity of the survey, we used Microsoft Forms and the scale option (to rank each risk on the three factors, detailed in Table 2) for data collection.

In total, we received 14 responses (6 academics, 4 in government roles, and 4 from non-government entities), which is a 39 % response rate. Although this is less than the response percentage hoped for, we opted to focus on the expert input provided rather than continue to expand the participant pool and thereby potentially involve more non-experts. As a result of this choice, we focus on expert input, utilizing the data provided. Participants had the option to select "Unable to Rate"

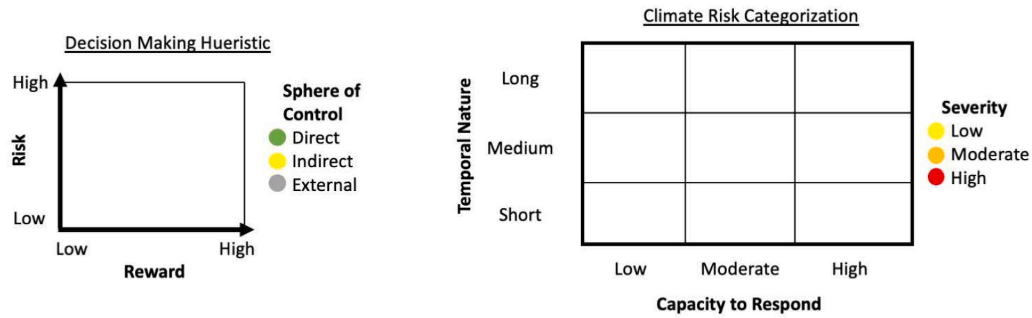


**Fig. 1.** Decision-making heuristic and climate risk categorization tools.

**Table 2**
Criteria for assessing risk impact, timescale and capacity to respond (Six-Point Scale).

| | Description | Scale |
|---|---|---|
| Severity of Risk Consequences | The scale of physical damage of the occurrence of the event/consequence on various aspects (public lives, health, properties, infrastructure, livelihood, provision of services, ecosystems, natural resources) | No Risk<br>Low Risk<br>Moderate Risk<br>High Risk<br>Extreme Risk<br>Unable to Rate* |
| Timescale of Risk | Occurrence of event/consequence (existing or projected) | Immediate<br>From 1 to 5 Years<br>From 5 to 10 Years<br>From 10 to 20 Years<br>From 20 to 50 Years<br>Unable to Rate* |
| Ability to Respond to Risk (Sphere of Control) | Institutional, infrastructural, technical, and actors' capacity to influence on or control over risk | No Control<br>Minimal Influence<br>Indirect Influence<br>Direct Influence<br>Direct Control<br>Unable to Rate* |

Source: based on Song and Lee (2022).
* Available in the forum for selection, excluded from results representation and analysis.

as a response, and in such a case, the data set was adjusted accordingly (i.e., not all responses necessarily include all participants).

### *Limitations*

Conducting a risk assessment using this methodology presents some limitations. One limitation is the language of the survey, as some leading experts in the country are proficient in Arabic. In our assessment, this limitation was minimal, as higher education in the State of Qatar is primarily conducted in English (including at: Hamad Bin Khalifa University, Qatar University, Texas A&M University at Qatar, Georgetown University in Qatar, Qatar Environment & Energy Research Institute), the exception is the Doha Institute for Graduate Studies and some undergraduate disciplines at Qatar University. A second limitation is that expert assessment introduces some subjectivity; this is expected given the methodology adopted, and exemplary of this is the diversity of responses received. While this subjectivity introduces some uncertainty, we find that this approach is best suited to answer the research question because the empirical alternative would be time- and cost-intensive (e.g., costing the severity of risks for all components of society). Empirically grounded efforts are on-going in the country, and those findings will be able to continue to advance risk and hazard assessments in the future. We believe the results of this paper support better-informed decision-making in the absence of such a comprehensive assessment, allowing for decision-making in the immediate pending the results of longer-term assessments. Relatedly, some metrics forced participants to make judgements, such as the timescale of impact when many hazards and risks are progressive in nature. Third, as earlier noted, experts are influenced not only by their domain expertise but also by the available evidence, which is uneven. There is a potential, therefore, that heavily researched risks and hazards are considered differently than those that are under-researched. Future studies could complement this study, conducting assessments as the evidence base advances with time.

## Existing country case study evidence

Qatar is a relatively small state (geographically at 11,521 sq km; demographically at 2.6 million) located on the coast of the Arabian Gulf (Cochrane and Al-Hababi, 2023b). The country is a member state of the GCC, along with Bahrain, Kuwait, Oman, Saudi Arabia, and the United Arab Emirates. Strategic leadership and hydrocarbon resources have resulted in rapid economic development, and the country now has one of the highest levels of GDP per capita globally and ranks "very high" in the Human Development Index. With regard to climate risks and hazards, Qatar faces a range of challenges, including: sea level rise, temperature rise, salination of groundwater, terrestrial and marine biodiversity loss, extreme weather events, and air quality, amongst others. The remainder of this section presents a synthesis of the available evidence on climate risks and hazards in Qatar, as identified in the systematic literature review.

### *General trends in climate risk assessment literature*

Climate change risk assessment literature has seen a thematic shift towards investigating specific areas, aspects, or sectors that are vulnerable. This trend may be attributed to the scale and complexity of climate risks that require a specialized assessment. Additionally, the availability of data and the ability to conduct specific, often technical, studies may contribute to this trend. Some strands of this literature, for instance, look into sea level rise (e.g., Wolters and Kuenzer, 2015) and flood hazards (e.g., Abdel-Mooty et al., 2023, 2022, 2021; Kim et al., 2018). As an example of this, Abdel-Mooty et al. (2023) provide an approach to categorize flooding risks based on the adaptation capabilities of communities in the United States and Canada and classify them based on 'losses and recovery time', or in other words, their resilience. Such categorization is argued to assist "decision-makers in developing proactive policies that focus on mitigation and prevention for a comprehensive risk management plan" (Abdel-Mooty et al., 2023, p.

236). Similar 'mapping' and categorization of water resources (namely aquifers) areas' vulnerability to climate change has also been drawn by some studies (e.g., Homolya et al., 2017). In this brief review, we highlight three emergent areas of research from the global arena that are of particular importance for the GCC member states.

Specific assessments have made important contributions to our understanding of risks and hazards, often identifying previously under-researched vulnerabilities. One such area is financial risk categorization, which includes the classification of physical risks and transition risks (e.g., Myklebust, 2022). The former relates to the direct impact of climate change on physical assets, while the latter refers to the potential losses and costs associated with transitioning to a low-emission society. These classifications have emerged as important factors for understanding the potential impact of climate change on financial systems and markets. By categorizing and quantifying the potential risks associated with climate change, policymakers, investors, and other stakeholders can better assess the financial implications of transitioning to a more sustainable society. The inclusion of threats that arise from the energy transition to low and zero carbon is particularly important for climate risk assessment in the context of the GCC member states, where economies are hydrocarbon-reliant and would need to deal with the global climate change mitigation measures that primarily revolve around decreasing fossil fuel consumption to cut carbon dioxide emissions.

A second example of an issue-specific advancement that has expanded our collective understanding of climate change impacts is viewing the collective risks from a national or international security risk perspective. As with the above example of financial risk categorization, understanding the security aspects related to climate change allow for the integration and participation of a broader set of stakeholders, and thereby aligned and integrated multi-sectoral responses. An example of this second case includes the work by Kameyama and Ono (2021), who emphasize the security aspect of climate risk categorization in the context of Japan. Although they do not attempt to prioritize the categories identified, nor do they look to the relevant adaptation and mitigation measures in place, a key takeaway is the inclusion of climate-induced conflicts and violence as well as natural environmental risks' implications on national security. Including such aspects in the climate risks assessment for Qatar –and Gulf– is of relevance, considering the regional security and stability challenges that climate change consequences could provoke or exacerbate.

A third example of literature on climate risks from the global scale that are relatively under-studied in the GCC member states is supply chain threats (Lima Adaptation Knowledge Initiative, 2015; Serdar et al., 2022). For example, Dasaklis and Pappis (2013) provide an overview of climate change risks at various supply chain stages (i.e., manufacturing, transportation, warehousing and storage, trading, and consumption and customer services). The identification and inclusion of climate change-related risks on the global supply chain in risk assessment in the context of Qatar are important, as the country has a substantial reliance on imports to attend to domestic needs and, accordingly, the interrelation of this aspect with cross-cutting issues (e.g., food security). This became particularly apparent when Qatar faced a land, sea, and air blockade by neighbouring nations from 2017 to 2021, from which the country previously obtained much of its food supply (Amery, 2019). These three examples (economic, security, and supply chains) were integrated into the methodology utilized in this study alongside more conventional categories of risks and hazards.

The need to consider impacts on systems, in addition to the specifics, is not a new consideration (e.g., Patz et al., 2008). Similarly, it is well-recognized that thematic and sectoral studies need to be integrated. On the latter, one example of an integrated approach to climate risk assessment is the work by Bustos (2020) and Bustos and Amigo (2019), which utilize variables of urban planning, demographics, governance, socioeconomics, and natural resources, which are used to assess community vulnerabilities. Similarly, Song and Lee (2022) developed a "systematic national-level risk assessment process and methodology" for the Republic of Korea (p. 198). The process they developed consisted of four steps: "(1) collecting scientific evidence, (2) making lists of preliminary risks, (3) making lists of risks and prioritizing, and (4) categorizing the risks" (Song and Lee, 2022, p. 198). Their findings highlight that climate change risks for certain sectors are well-researched (namely industry/energy, agriculture, water, and ecosystems) yet comparative under-researched in others. Three components of risks (hazard, exposure, and vulnerability) were identified, and 93 risks were concluded and prioritized based on an expert survey. The findings highlight "that only one-third of the risks can be dealt with existing measures and policies," and more than one-third of these risks require new measures (Song and Lee, 2022, p. 198). Country-level studies, such as this one, allow for localization of evidence utilization and expertise and enable better-informed prioritization of action and investment. For the State of Qatar, integrated approaches have included utilizing nexus approaches for analysis, such as the energy-food-water nexus (Bilal et al., 2021; Ben Hassen et al., 2020; Woldesellasse et al., 2018). However, as earlier noted, we are aware of no study for the State of Qatar that seeks to categorize and prioritize risks and hazards for the country. This paper addresses this gap by drawing on these global efforts while being guided by categorizations that emerge from region- and country-specific evidence.

*Climate risk assessment in qatar: previous efforts and existing challenges*

Although climate risk assessments may not be considered completely novel in Qatar, they remain rarely conducted (e.g., Serdar et al., 2022). Moreover, to our knowledge, there has been no national climate risk assessment that is inclusive of all climate change impacts, risks, and hazards, in which they are categorized or prioritized based on severity, timescale, and state's ability to respond. However, important work has been done in the form of sectoral assessments and for specific activities. These have been conducted by government entities as well as researchers; here, we survey three examples of this and the insights emerging from them.

From what was formerly the Ministry of Municipality and Environment, since divided into the Ministry of Municipality and the Ministry of Environment and Climate Change, a climate risk assessment was carried out as part of the preparation for the climate change strategy. This was to be utilized for urban planning and urban development (an effort led by a consultant, GHD Global PTY LTD; Ministry of Municipality and Environment, 2023b). The strategy document identifies climate change 'threats' broadly (i.e. sea level rise and flooding, increasing temperature, and decline of biodiversity) and lists the measurement against each within the urban planning and development sector (Ministry of Municipality and Environment, 2023a). The strategy document does not indicate a certain prioritization or categorization of these risks, whether based on a temporal or severity analysis. Indeed, unclear prioritization has been cited as one of the factors underpinning the failure to meet the environmental development targets of the first National Development Strategy 2011-2016 (Ministry of Development Planning and Statistics, 2018). A second example of such an assessment also comes from the government, produced by the Public Works Authority, called *Ashgal*, which is the government agency responsible for planning and constructing infrastructure projects in the country. It developed a hotspot map for flooding vulnerable areas, which is used to inform construction and infrastructure development. The method used in their assessment or mapping relied on the verified complaints and reports they received regarding rainwater excesses and flash floods (Serdar et al., 2022). In both of these cases, a specific use framed the objectives and utilization. These assessments are important but need to be complemented with broader integrated studies to support a whole-of-government approach to prioritization.

From the academic sector, researchers have conducted risk assessments, and for the State of Qatar, the most notable of these is the work done by Serdar et al. (2022), which (like the Public Works Authority) focuses on flooding risk but broadens the geographic focus to cover the entire country. The study highlights the association between urban areas and flooding susceptibility in Qatar's eight provinces. It identifies provinces with high flood susceptibility and provides recommendations to alleviate their vulnerability. Carrying out a general or specific climate risk assessment is often hindered by the lack of necessary data and information. Indeed, climate risk assessment in the GCC member states, and in Qatar in particular, is hindered by the persistent challenge of a lack of scientific evidence on climate change impacts specific to the local conditions. This is not due to a lack of data per se but also due to the fragmentation of baseline data, a lack of standardized methodologies and integrated approaches to consolidate information, data incomprehensiveness, and inadequate monitoring and assessing technical capacities are among the issues contributing to the knowledge gaps in the literature concerning climate change in the GCC countries (Lima Adaptation Knowledge Initiative, 2015). Establishing an approach to address these knowledge gaps are required for more effective and evidence-informed climate change risk management (European Commission, 2013). Such gaps can be bridged through inputs from respective experts (whether via surveys, workshops, and similar means) throughout the climate risk assessment process (Song and Lee, 2022; Bustos, 2020; Lima Adaptation Knowledge Initiative, 2015), although identifying and prioritizing the risks will remain subject to those experts' opinions, the inclusion of their feedback provides more comprehensive assessments in comparison to those that solely rely on available data and information. Part of the authors' earlier project, an edited book (Cochrane and Al-Hababi, 2023a), attempted to address knowledge gaps specific to the State of Qatar; this research effort builds upon that study to categorize and prioritize the available evidence to support decision-making.

*Climate change-induced challenges or risks for qatar*

The availability of evidence for Qatar is uneven, with some sectors being relatively more researched (e.g., impacts on groundwater, flood risk) in comparison to others (e.g., terrestrial biodiversity). In this subsection, we briefly survey that literature, which is relevant because risk assessments are also relative to knowledge availability, including when surveying experts. To exemplify the depth of study for some issues, we assess the available evidence and reflect upon areas that are relatively under-researched.

An area of comparative strength in terms of evidence availability relates to groundwater and how it has been, and will be, impacted by climatic changes and anthropogenic activities. The expected increase in average temperatures, and the increase of evaporation that would be caused combined with rapid urbanization, and overexploitation would all lead to a decline in groundwater quantity and quality (Ajjur and Al-Ghamdi, 2022a, 2022b, 2022c; Serdar et al., 2022; Bilal et al., 2021; Awadh et al., 2021; Ahmad and Al-Ghouti, 2020; Salimi and Al-Ghamdi, 2020; Yan and Mohammadian, 2020; Husain and Chaudhary, 2008; Chaudhary and Husain, 2006). The annual groundwater mean is expected to decrease under all climate change Representative Concentration Pathway (RCP) scenarios, which means that there will be a deficit in natural water resources (Ajjur and Al-Ghamdi, 2022b). The consequences of groundwater and aquifers unreliability include the inability to meet the increasing water requirements and the deterioration of soil conditions (Ajjur and Al-Ghamdi, 2022b; Bilal et al., 2021; Yan and Mohammadian, 2020; Alsheyab, 2017; Ibrahim and Lal, 2013). Other significant consequences include the implication of groundwater depletion on the already struggling agricultural activities (IPCC, 2022; Ajjur and Al-Ghamdi, 2022c), which is of critical importance since most land in Qatar is not suitable for conventional agriculture (Bilal et al., 2021; Ben Hassen et a., 2020). As earlier noted, increasing demand and fewer groundwater resources may result in increased energy demand, as domestic water use is largely sourced from desalination (Bilal et al., 2021; Salimi and Al-Ghamdi, 2020), making this challenge one of national importance (Ajjur and Al-Ghamdi, 2022c; Bilal et al., 2021; Ben Hassen et al., 2020; Al-Saidi, 2019). Research on groundwater has recommended minimizing the abstraction of aquifers, creating and applying aquifer management and recharging projects (Ajjur and Al-Ghamdi, 2022b), using desalinated and treated wastewater in agricultural activities as well as drip irrigation techniques to reduce the pressure on groundwater resources (Bilal et al., 2021; Awadh et al., 2021), and developing water-use tariff structures and raising awareness campaigns for farmers to change water use behaviors (Ahmad and Al-Ghouti, 2020).

Another well-researched issue related to climate change in Qatar is flooding and the probability and implications of this risk on critical functions and sectors. The annual rainfall has been showing increasing trends and is expected to increase by 50 percent, from the current, by the 2040s and onward, and so are the frequency and intensity of extreme rainfall events (Al Mamoon et al., 2019; Al Mamoon and Rahman, 2017; Al Mamoon et al., 2015). At the same time, the country's stormwater drainage system is limited and is mainly constituted of some subsurface chambers and pipes that divert excess runoff. The system proved inefficient during extreme rain events in 2015 and 2018, in which flash floods were witnessed (Ajjur and Al-Ghamdi, 2022a). The climatic changes in annual rainfall levels combined with past and current urban growth patterns –in which vegetation is reduced, bare lands are covered, impervious surfaces are expanded, and pervious surfaces are decreased– would lead to more surface runoff accumulations and, accordingly, higher flooding risks (Ajjur and Al-Ghamdi, 2022a; Serdar et al., 2022). Flooding poses risks not only to the resilience of infrastructure and stormwater systems but also to the whole built-up environment (Ajjur and Al-Ghamdi, 2022a, 2022b; Al Mamoon et al., 2019; Al-Saidi, 2019). The impacts of sea level rise (as well as winds and coastal erosion; Shirkhani et al., 2016) compound flooding risks (Ben Hassen et al., 2020; Ibrahim and Lal, 2013; Fragu et al., 2009; Husain and Chaudhary, 2008). The recommendations emerging from these studies include adapting to flooding by establishing stormwater drainage systems to incorporating flood risk in urban planning and development and integrated urban design with purpose-built spaces to manage water and reduce flood risk.

Strong winds and waves have the potential to harm marine ecosystems, especially in coastal areas with seafloor disruption and more suspended sediments near the surface, which would lead to more sunlight being reflected by the water and, accordingly, a change in the habitat system (Shirkhani et al., 2016). The rise in sea level, along with increases in average temperatures, and shifts in seawater salinity and oxygen, would have a significant impact on marine biodiversity as well. Some studies highlight that the habitat suitability for numerous marine species that are of importance to fisheries is declining –including coral reefs, seagrass beds, mangroves, and fish species– and, accordingly, these marine species' populations are projected to undergo major declines, and their spatial distributions are disrupted (IPCC, 2022; Wabnitz et al., 2018; Coles and Riegl, 2013). Moreover, local extinction rates are expected to increase considerably along the coasts of Qatar (Elobaid et al., 2022; Chatting et al., 2021; Nesterov et al., 2021; Ali et al., 2020; Ben Hassen et al., 2020; Cavalcantea et al., 2020; Al-Khayat et al., 2018; Wabnitz et al., 2018; Alsheyab, 2017; Burt et al., 2016; Pilcher et al., 2015; Coles and Riegl, 2013; Fragu et al., 2009; Husain and Chaudhary, 2008). Beyond the biodiversity concern, such consequences mean that the maximum fisheries catch potential is going to decrease, which also means less fish available for local consumption and export activities, adversely impacting, therefore, food security and income generation (IPCC, 2022; Al-Saidi, 2019; Ali et al., 2020; Wabnitz et al., 2018).

The expected increased frequency, intensity and duration of heatwaves would increase building annual energy demand for cooling (Ajjur and Al-Ghamdi, 2022c, 2020; Salimi and Al-Ghamdi, 2020). This also poses a systems risk as demand in extreme heat waves could lead to overloading or damaging the electrical power systems (Andric and Al-Ghamdi, 2020; Gastli et al., 2013). Relatedly, since most input to the electricity grid is from natural gas, this would result in an increase in natural gas 'self-consumption' and thus lowered exports and an increase in buildings' environmental footprint as more carbon dioxide would be omitted due to such demand and supply behaviours. Furthermore, this would result in more discharges from desalination plants, affecting local marine ecosystems (Andric and Al-Ghamdi, 2020). Moreover, the increase in seawater temperature would also affect the efficiency of industrial facilities such as petrochemical, desalination, and power plants that use seawater for cooling purposes and raise their operating costs as their energy demand would grow and as the duration and frequency of their downtime would increase with increment of extreme water temperature events (Nesterov et al., 2021; Al-Saidi, 2019). Opportunities exist for mitigating these risks, such as expanding solar energy sources (Tahir et al., 2022); in 2022, the country finished a facility that can meet 10 percent of peak energy demand (TotalEnergies, 2022).

Relatedly, since the country is expected to witness more hot days and heat waves, cases of heat- or sun-stroke, cardiovascular disease, respiratory issues, decreased kidney function, adverse birth outcomes, and vector-borne disease are expected to increase among the population (Ferwati et al., 2019; Alsheyab, 2017; Cheng et al., 2017; Fragu et al., 2009; Husain and Chaudhary, 2008). Climatic changes are also suggested to contribute to the emergence and rapid spread of epidemic diseases in the region (Buliva et al., 2017). Further analysis by Al-Mohannadi et al. (2016) highlights that the increase in temperature and humidity could result in a decline in physical activity of people, which may have serious health implications. Moreover, the increased frequency and intensity of dust storms would lead to more motor vehicle accidents, and medical facilities would be experiencing a surge in respiratory, vehicular trauma and ophthalmic cases that could sometimes be beyond those facilities' capacity (Middleton et al., 2021). All of these health consequences will also have economic impacts (Ferwati et al., 2019).

Some studies perhaps did not focus on Qatar in their analysis, but they indirectly shed light on how climate change could feed the prolonged regional instability in Africa –in the Great Lake region, where many of Qatar's investments are located. The region's stability is important to Qatar, considering that the investments there are utilized to provide agricultural and horticultural products for the population (Ngambouk et al., 2021). Therefore, regional instability and political conflict not only hold a financial risk but also contribute to food security. This has been highlighted by Ben Hassen et al. (2020) and Ajibade et al. (2020), who highlight that because Qatar is heavily reliant on food imports, supply chain disruptions elsewhere have direct domestic impacts. As noted above, climate stressors might increase disruptions, including putting pressure on resources and the potential for conflict (Luomi, 2011).

Climate change has become a significant variable to the state's stability for all of the above-mentioned reasons. However, there may be other, less researched, areas that are also of critical importance. These gaps have been noted by Pal et al. (2023) and Cochrane and Al-Hababi (2023b), which include impacts to key sectors (e.g., aviation), disruptions to international supply chains and the politicization of trade, social aspects of sustainability, lifestyle and consumption patterns, and emergency planning for systems failure and/or responding to unexpected tipping points.

## Findings

Having synthesized the available evidence on climate risks and hazards, this section analyses the results of the expert survey, which categorizes and assesses the risks and hazards. The results of the expert survey are presented and integrated with the relevant evidence that were identified in the systematic literature review. In what follows, we analyse the results using different approaches, first with variables arranged in comparison to each other (in stacked horizontal bar charts), which is followed by a merging of data sets (in scatter plots that combine two variables) for easier visual assessment and interpretation.

The first assessment was exploring the severity or impact that the risks pose to the State of Qatar (Fig. 2). Both ends of the spectrum are insightful. For example, the capacity to respond was viewed as having

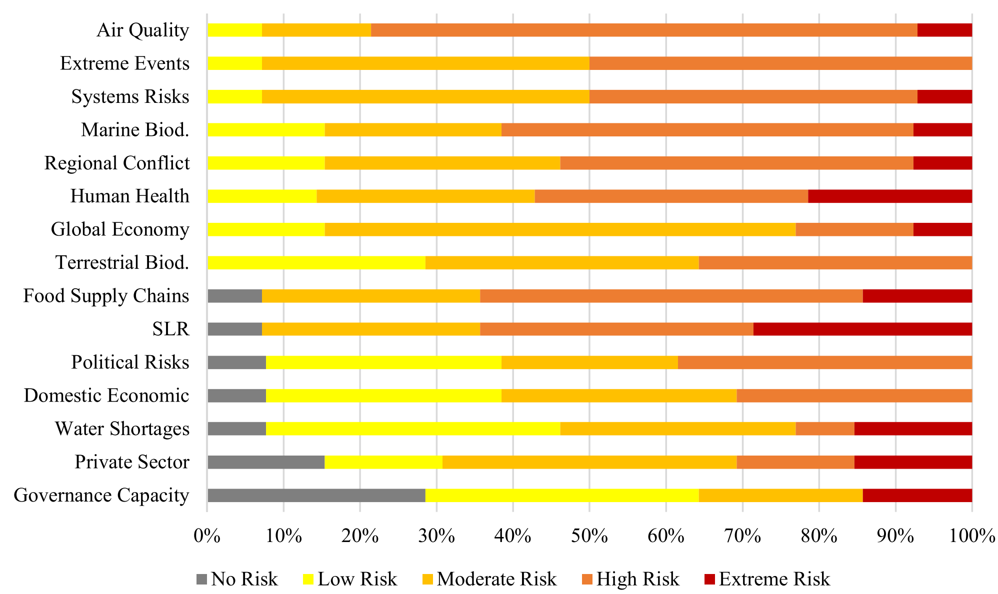


**Fig. 2.** Categorization of climate change risks based on severity or impact.

low or no risk by the majority. This finding can be validated by other available assessments, such as that conducted by ND-GAIN (2023), which findings indicate that Qatar has a high readiness score. Relatedly, those services or sectors related to the government or those regulated by it similarly were viewed as having low to no risk (e.g., water shortages, domestic economy, private sector readiness, political risks). Conversely, the risks deemed to have the highest extreme or high risk included sea level rise, impacts on human health, and disruptions to food supply chains. These are the only three that the majority determined to be of extreme or high risk in terms of impact. Looking into how their severity is outlined in existing evidence, studies highlight that the impacts of sea level rise extend beyond those that relate to threats to built environment and compounding flooding risks (Ben Hassen et al., 2020; Ibrahim and Lal, 2013; Fragu et al., 2009; Husain and Chaudhary, 2008) to marine biodiversity loss. The rise in sea level (along with increases in average temperatures, and shifts in seawater salinity and oxygen) is expected to contribute to changing habitat suitability for numerous marine species and, hence, lead to a decline in their populations (Wabnitz et al., 2018; Coles and Riegl, 2013), reflecting the interconnection between the two challenges. Evidence on the impacts of climatic changes on human health highlights similar interconnections between risks. The threats extend beyond increases in health issues and the spread of various diseases to burdens on the health system and adverse influences on economic productivity (Middleton et al., 2021; Ferwati et al., 2019; Alsheyab, 2017; Buliva et al., 2017; Cheng et al., 2017; Al-Mohannadi et al., 2016; Fragu et al., 2009; Husain and Chaudhary, 2008). The existing evidence base also reflects on the threat climate change poses on food supply chains for Qatar as a country that imports the vast majority of its food, and the vulnerability to impacts of supply chain disruptions elsewhere (Ben Hassen et al., 2020; Ajibade et al., 2020). They highlight that climate stressors might increase disruptions, including putting pressure on resources and the potential for conflict in the region (Ngambouk et al., 2021; Luomi, 2011). Disruption of food supply chains here interconnects with challenges that relate to regional stability (Ngambouk et al., 2021; Ben Hassen et al., 2020; Ajibade et al., 2020; Luomi, 2011).

For the validation of these assessments, the ND-GAIN Index confirms that the majority of the population resides in low-lying areas (where the elevation is 5m of less). However, the Index is not particularly well suited for the flood hazard, as it is measured by 5 consecutive days of rainfall, which may not be the most suitable measure given that past flood events have occurred as a result of shorter, but more extreme, forms of rainfall (as occurred in 2018). This is an example of why country experts add value to risk assessments that compilations of globally standardized data may not provide.

The other two extreme and high risks, as determined by the majority of experts, are impacts on human health and food insecurity related to global supply chain disruptions. For the former, the literature review presented above validates this risk (we refer readers to that section for those details and do not repeat them here). Measures related to food supply in the ND-GAIN Index are minimal; however, insights from the Global Food Security Index (2022) and the National Food Security Strategy (FSD, 2020) suggest that food trade import dependency combined with low levels of country sources of that trade present risks for food security. Neither, however, sufficiently take into account the regional and international political and conflict risks that could affect these trade flows, which the experts surveyed in this study have suggested amplify this risk.

The occurrence of these challenges varies, as per expert assessment, with some having immediate impacts and others appearing in the longer term (20–50 years from the present), as shown in Fig. 3. None of the risks was deemed by the experts as having impacts in the immediate and short term (1–5 years), although air quality and political risks are the most immediate. This result aligns with existing evidence on air quality in the state. Qatar is experiencing high annual mean concentrations of nitrogen dioxide ($NO_2$), particulate matter of a diameter equal to or smaller than 10 µm ($PM_{10}$), and those equal to or smaller than 2.5 µm ($PM_{2.5}$). According to the World Health Organization (WHO) database, in 2022 (World Health Organization, 2022), Doha recorded 150 of $PM_{10}$ ($\mu g/m^3$), which is way higher than the organization's guideline value of 15 µg/m3 for $PM_{10}$. The city recorded 38 in terms of $PM_{2.5}$ ($\mu g/m^3$), which is also higher than WHO's defined guideline value of 5 $PM_{2.5}$ ($\mu g/m^3$). 28 of $NO_2$ ($\mu g/m^3$) was recorded, which is above the specified guiding value of 10 $NO_2$ ($\mu g/m^3$) (2022) as well. Global evidence suggests that climatic changes, and the rise in temperature in particular, are expected to reduce air quality further in urban cities such as Doha (Teather et al., 2013).

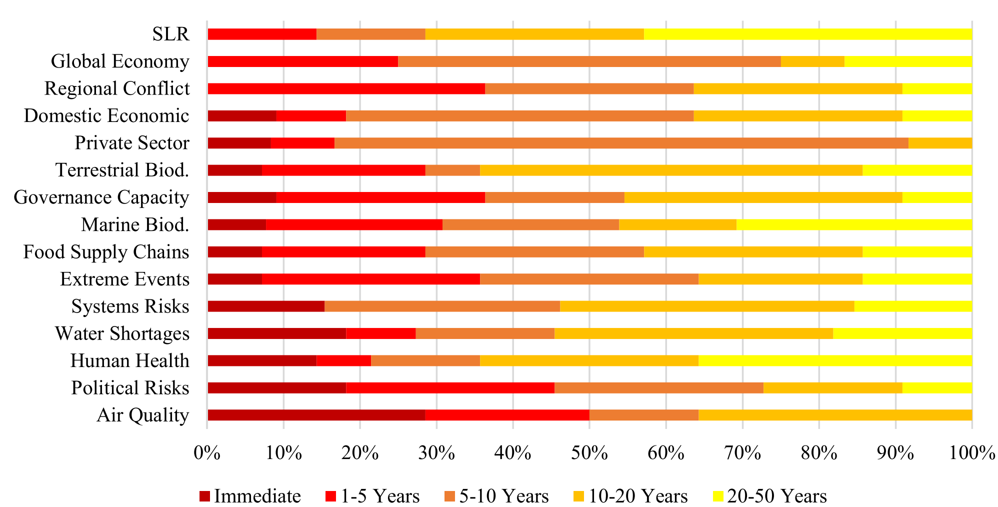


**Fig. 3.** Categorization of climate change risks based on timescales.

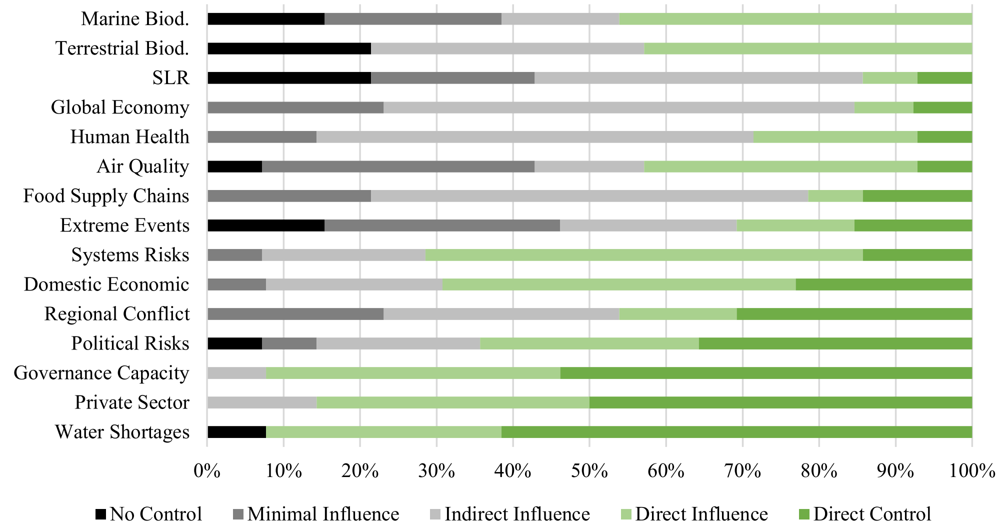


**Fig. 4.** Categorization of climate change risks based on actors' ability to respond.

Although sea level rise was deemed to have a high or extreme impact (Fig. 2), the appearance of this risk is suggested by the experts to only occur in the longer term (10–20 years or 20–50 years' timeframes). Akin to temperature increase, sea level rise occurs progressively, and this is, therefore, the point at which this risk or hazard has a significant negative impact on the country. This aligns with other available sources (e.g., World Bank, 2023). This is followed by impacts on human health, impacts on marine biodiversity, and impacts on terrestrial biodiversity, all of which have impacts to the long-term increase of temperatures as well as extreme weather events, notably heat waves (e.g., Ajjur and Al-Ghamdi, 2022c; Nesterov et al., 2021).

The third dimension that experts categorized risks on was the ability to respond to these risks, which draws on literature related to spheres of control (no control, minimal influence, indirect influence, direct influence, direct control; Fig. 4). As with Fig. 1, many of the risks that were deemed to be within the direct control or direct influence included those related to government-provided services or government-regulated activities (water availability, private sector capacity, governance capacity, and political risks; all viewed as within the realm of direct influence or direct control by a majority of experts). The risks with the least ability for control or direct influence were sea level rise, extreme weather events, and air quality. Existing evidence misses such insights, as assessments are often done at a regional scale. In the IPCC Sixth Assessment Report, for instance, Qatar is looked at within the broader context of the West Asian region, which has been characterized by low capacity to cope with climate risks and, hence, was regarded among the most vulnerable regions (2022, p. 1202). However, some of the global indexes that formed the basis for this conclusion in IPCC 6$^{th}$ Report suggest otherwise for the specific case of Qatar. For example, the 2019 WorldRiskIndex, which measures exposure and vulnerability to extreme events, lists Qatar as the country with the lowest risk worldwide, with low degrees in terms of vulnerability as well as lack of coping and

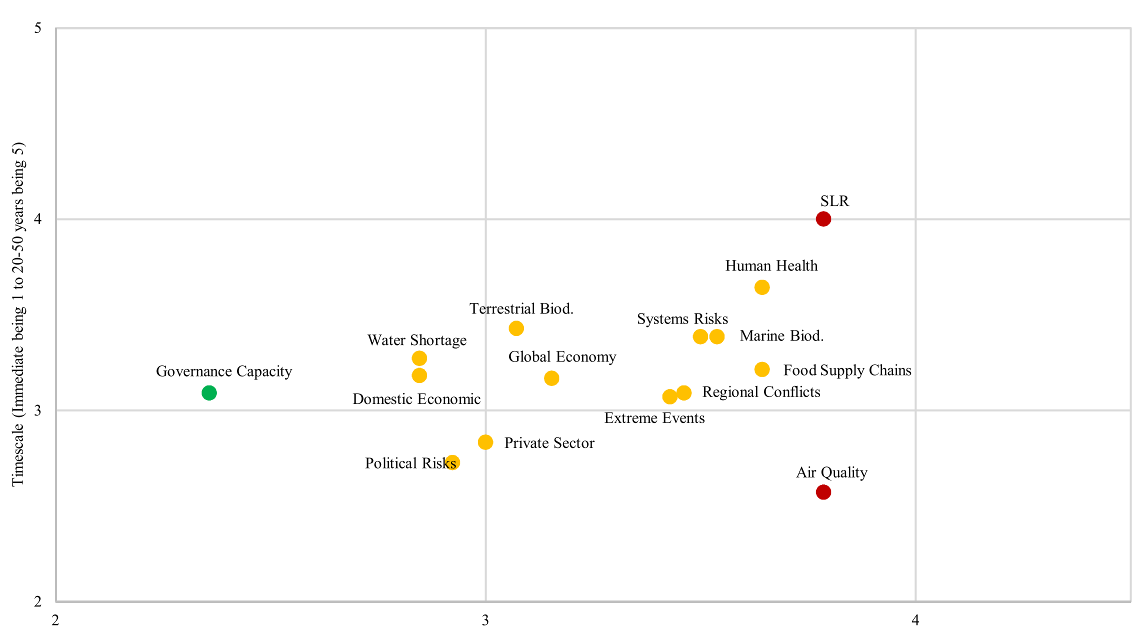


**Fig. 5.** Risks' distribution: impact vs timescale.

adaptative capacities (Radtke and Weller, 2019). INFORM Risk Index, for the same year, too, gives a similar ranking in terms of Qatar's capacity to cope, with a score of 2.5 (with 0 more reliable and 10 less reliable) (2019, p. 36). These two indexes provide insights into the overall capacity of the states to respond to risks but not in specific to a set of climate risks, as this paper attempts to do.

The above risk assessments categorize risks in comparison to other risks; in what follows, we combine the categorizations in scatter plots to merge the data, allowing for more detailed comparisons that take into account multiple variables. In Fig. 5, the timescale (vertical axis) is plotted alongside the severity of the impact (horizontal axis). This analysis approach highlights unique results from the study, allowing for a clustering of combined variables and the identification of outliers. An example of this is the relative strength that experts view with regard to the government's capacity to respond and the comparatively low risk that is present from a timescale perspective. On the other hand, air quality and sea level rise emerge as outliers as both having a high or extreme impact but occurring over different timescales (air quality in the shorter term while sea level rise in the coming decades).

Maintaining impact on the horizonal axis and adding ability to respond as the vertical axis (Fig. 6) affirms the above-noted clustering of government services or government-regulated sectors (governance capacity, water, domestic economy, private sector, and political risks) as being of lower risk and relatedly within a greater sphere of control by the government and key stakeholders. At the other end of the spectrum, as affirmed in the above figures, the challenges with a low level of control (extreme events, marine biodiversity, air quality, sea level rise) are also those that are viewed as posing the greatest severity of impact.

The last combination of variables (Fig. 7) plots the timescale on the horizontal axis and the ability to respond on the vertical axis. Akin to Fig. 6, three clusters emerge that align with the earlier finding and reinforce the general trends of the categorization of these risks and hazards. Risks plotted in the upper regions are of a timescale between 1 to 5 and 5 to 10 years, and a government's ability to respond ranging between direct influence and direct control. Whereas risks located in the middle regions of the Figure have a timescale between 1 to 5 and 5 to 10 years, and a government's ability to respond ranging between indirect and direct influence. Risks situated at the lower regions are of a timescale between 1 to 5 and 10 to 20 years, with the government sphere of control ranging between minimal to indirect influence.

Categorizing risks by variables allows for an identification of strengths and challenges based on localized knowledge. While some variables, such as governance capacity and water supply, were deemed a low risk and having a high ability to respond, others were identified that require more attention, such as sea level rise and resulting risks such as flooding. As noted in the review of evidence, this is an area that has attracted government and research attention; however, this assessment suggests that the response does not meet the required risks and more is required to be done to reduce the long-term risks. In addition to building upon strengths and identifying gaps, this expert survey identified unique aspects for the government, which are not typical for climate change responses. For example, the experts highlight that many risks are beyond the direct control of the government and domestic stakeholders (e.g., global economic shocks, marine biodiversity and air quality), requiring regional and international cooperation. Examples of this might include a coalition of countries sharing the coastal waters of the Gulf (Bahrain, Iran, Iraq, Kuwait, Oman, Qatar, UAE) cooperating on issues of mutual interest, for which each individually could not accomplish alone. Other existing intergovernmental organizations, including the GCC, could also be utilized for this purpose. A second example of a less common prioritized challenge for climate change response relates to global supply chains, both for the country's exports (and economic stability) and imports (for food security). Mitigating these risks also requires investing in regional and international cooperation, and specifically in peace and stability. This is something that the State of Qatar has been heavily involved in (e.g., the negotiations with the Taliban in Afghanistan), which it might strategically strengthen in combination with its official aid agency, the Qatar Fund for Development, as well as its sovereign wealth fund (the Qatar Investment Authority). These examples highlight the unique results and recommendations that emerge when risk

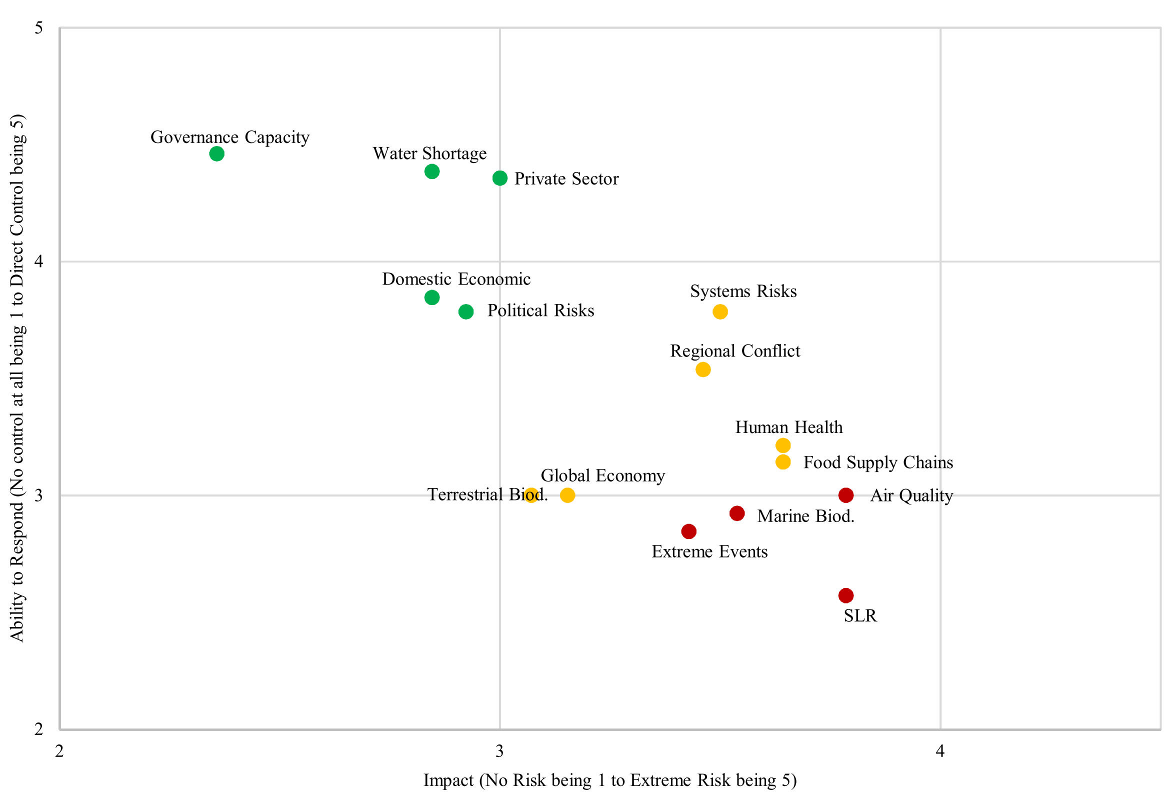


**Fig. 6.** Risks' distribution: impact vs ability to respond.

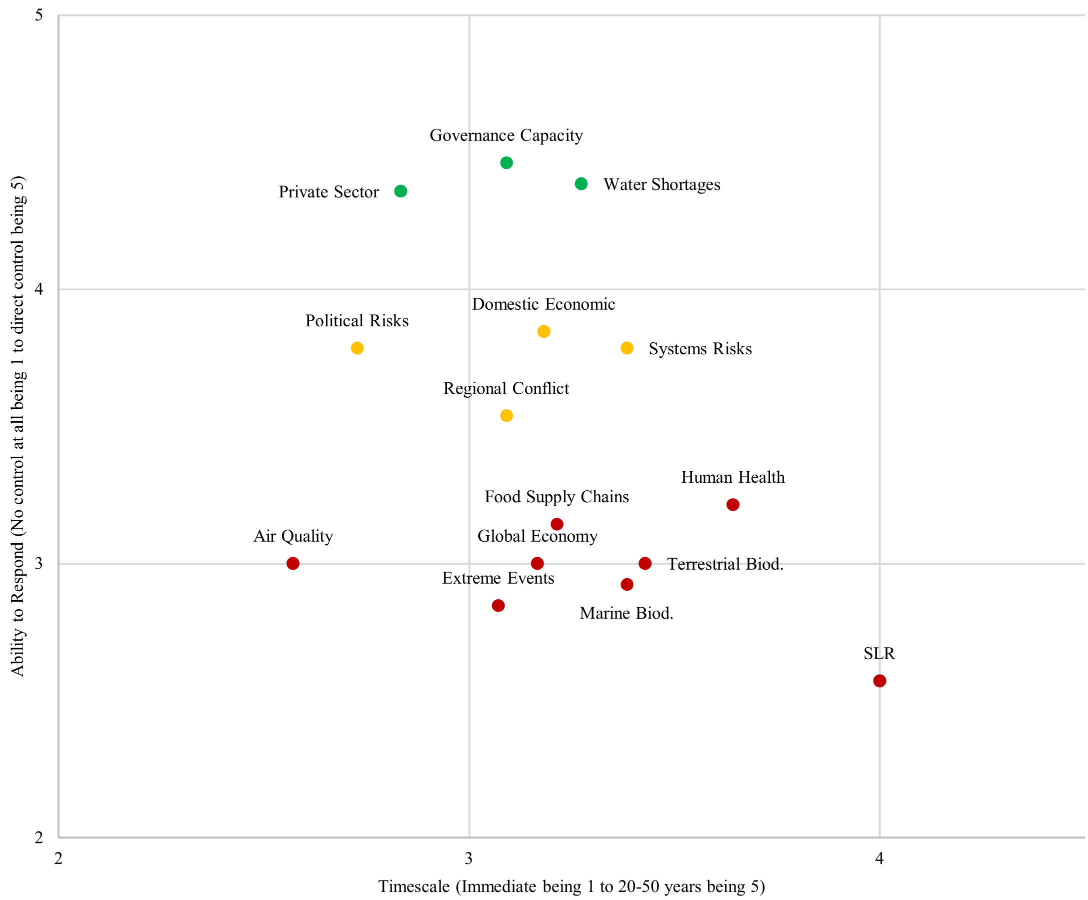


**Fig. 7.** Risks' distribution: timescale vs ability to respond.

assessments are based upon local expertise and localized prioritizations, which may otherwise be missed in standardized assessments used globally (which we do not suggest are not helpful but need to be used in parallel with country-specific assessments).

## Conclusion

Decades of research have accumulated on the causes and consequences of climate change, as well as a wide range of mitigation and adaptation options and pathways. This evidence base, however, is globally uneven, with some countries having the advantage of a wealth of country-specific knowledge, while others have comparatively less. In comparison to other developed countries, the State of Qatar has a comparatively smaller evidence base to support decision-making on climate risks and hazards. The types and severity of risks and hazards differ based on geography, meaning that country-specific knowledge and localized response prioritization are critical for supporting effective and impactful decision-making. The merit of this study is that it utilizes what is available to enable evidence-informed decision-making, while also emphasizing the need for additional research. To do this, tools and methodologies are needed for risk prioritization, which are adapted and implemented at multiple scales. This paper developed a risk categorization tool and decision support heuristic adapted for the Gulf region and was applied specifically for the State of Qatar. With the limitations of available research, combined with the need to make decisions, this study draws on expert assessment to support the prioritization of action and investment. The literature identifies a range of types of risks and hazards, and the expert assessment categorizes these risks and hazards relative to each other. The results of this study allow decision-makers to compare risks and hazards when making decisions about resource allocation and policy interventions. The results enabled the identification of strengths and gaps, as well as interventions unique for the region, to address country-specific vulnerabilities. While the application of this study is specific to one country, the methodology and assessment approach could be applied in other contexts to enable more evidence-informed decision-making. Moreover, to address climate-related knowledge gaps and their implication on relevant decision-making in certain contexts, future research could initially look into identifying risks, sectors, and areas that lack fundamental research to drive attention towards them.

## CRediT authorship contribution statement

**Logan Cochrane:** Conceptualization, Data curation, Formal analysis, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Reem Al-Hababi:** Data curation, Formal analysis, Validation, Visualization, Writing – original draft, Writing – review & editing.

## Declaration of Competing Interest

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

## Data availability

Data will be made available on request.

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