Assessing Infrastructure Resilience in Small Islands: Methodology Proposal

Fabiane Aline Acordes
German Aerospace Center &
University of Wuppertal
fabiane.acordes@dlr.de

Sylvia Bach
Institute for Public Safety and Emergency Management, University of Wuppertal
sbach@uni-wuppertal.de

Frank Fiedrich
Institute for Public Safety and Emergency Management, University of Wuppertal
fiedrich@uni-wuppertal.de

Frank Sill Torres
Institute for Protection of Maritime Infrastructures, German Aerospace Center
frank.silltorres@dlr.de

ABSTRACT

Small islands face unique challenges when it comes to increasing the resilience of their infrastructure systems, especially against climate-related disruptions. This proposal outlines a resilience-focused methodology for assessing critical infrastructure in such environments, integrating four interrelated phases: (1) literature review and documentary analysis to understand the context and existing knowledge, (2) conducting participatory workshops for local insights, (3) semi-structured interviews for in-depth perspectives, and (4) data analysis to integrate findings. This methodology, centered on participatory approaches, seeks to explore the dynamics of the impacts of disasters on the infrastructure of small islands. Developed as part of doctoral research at the German Aerospace Center and the University of Wuppertal, this methodology will be tested on Germany's East Frisian Islands from 2023 to 2026. Its emphasis on stakeholder involvement aims to bridge gaps in existing research and provide practical strategies to enhance the long-term disaster resilience of small islands communities.

Keywords

Infrastructure resilience, small islands, participatory approach, critical infrastructure, disaster impacts.

INTRODUCTION

Recent years have witnessed significant changes in global climate patterns, resulting in increased risks of adverse weather events and environmental change (Mycoo et al., 2022). These changes have profound implications, affecting various facets of society, from local livelihoods to infrastructure (Moser et al., 2012; Roy et al., 2023).

Among the most susceptible to these impacts are small islands, which face distinct challenges due to their physical exposure and limited space and resources (Kelman, 2010; Pörtner et al., 2022; Rampengan et al., 2014). Environmental changes also pose significant threats to the stability and operability of critical infrastructure (CI), such as public water services, energy supply, communication networks and transport, which are crucial to the functioning and security of island communities.

Disruptions caused by disasters can manifest themselves in various ways, including physical damage to infrastructure assets, disruptions to essential services such as transport and utilities, and socio-economic consequences such as loss of livelihoods and population displacement. In addition, the interconnected nature of infrastructure systems exacerbates the cascading effects of disaster disruptions, amplifying their overall impact on community well-being (Labaka et al., 2014; Pal et al., 2023).

As these disasters are often unforeseen in terms of time, magnitude and location, managing the resilience of CI becomes crucially important. Within this context, resilience refers to the capacity of a system to recover from

challenges or disruptive events (Cantelmi et al., 2021).

Managing the resilience of critical infrastructure involves considering available risk management methods to integrate different perspectives and address complexity and uncertainty (Kröger & Zio, 2011). However, small islands encounter additional obstacles when increasing infrastructure resilience due to factors such as financial constraints, geographical limitations and dependence on external aid for disaster response and recovery (Pörtner et al., 2022; Rampengan et al., 2014).

Numerous studies have explored the resilience of CIs, but only a few have focused on small islands as a distinct system. In addition, studies addressing these impacts often take a mono sectoral approach, focusing only on specific sectors and neglecting the cascading effects, dependencies, and wider social impacts of disruptions (Bruijn et al., 2019).

These issues highlight the need for innovative methodologies that not only understand the intricate dynamics of disaster disruptions to infrastructure systems but also facilitate the formulation of context-specific resilience strategies for small islands.

In addressing such challenges, participatory engagement emerges as a key function in building resilience in small island communities. By actively involving stakeholders in decision-making processes, participatory approaches benefit from local knowledge and insights, thus facilitating the development of context-specific resilience strategies (Jamero et al., 2018).

In this study, a resilience-focused methodology will be developed and proposed to analyze the impacts disaster events on CIs and societal well-being in small island contexts. By examining the impacts, duration, severity, and dependencies, the aim is to propose a methodology to measure and/or enhance resilience and safeguard the sustainability of small islands. Through a participatory approach, stakeholders are involved in developing strategies to strengthen infrastructure resilience and mitigate disaster disruptions.

CURRENT STATE OF THE ART

Disaster Impacts in the Context of Small Islands

Although there is no clear definition in the literature in terms of population or size, small islands can be broadly classified into three types (Petzold & Magnan, 2019): Small Island Developing States (SIDS), Dependent Islands, and Semi-Autonomous Subnational Island Jurisdictions (SNIJs). SIDS are recognized for their vulnerability to climate change and have been prominent in international discussions and research on this topic. Dependent islands are territories that, while not independent, are part of larger continental states and often have limited access to international aid, relying instead on national development strategies and funds. SNIJs possess a degree of autonomous government and are involved in a formal political partnership with a larger state, but they may face challenges such as limited regional cooperation and internal migration.

Despite socio-political differences, these island types share common issues related to climate change and general vulnerability due to their unique geographical and socio-economic characteristics. These impacts encompass shifts in atmospheric and oceanic conditions, leading to phenomena like sea level rise, ocean warming, ocean acidification, and alterations in extreme weather patterns such tropical cyclones and hurricanes (Nurse et al., 2014).

Extreme weather events, like hurricanes and cyclones, can inflict severe damage on small island infrastructure, including critical systems like energy, water, and sanitation (Nurse et al., 2014). Coastal infrastructure is especially vulnerable, with storm surges and high winds threatening seawalls, roads, and buildings near the shore. Limited resources for emergency response and reconstruction further exacerbate the challenges faced by these islands.

The primary effects of climate change also trigger secondary impacts, such as saltwater intrusion into groundwater and soils, marine flooding, and shifts in species distribution due to temperature and precipitation changes (Holding et al., 2016). Intrusion of saltwater can degrade water infrastructure and agricultural land, posing threats to food and water security.

From a social aspect, common challenges across small islands include limited regional-scale climate information, governance complexities, and economic vulnerabilities. These islands often rely heavily on natural resources like fisheries and tourism, making them particularly susceptible to climate-induced disruptions (Hiwasaki et al. 2014). Population dynamics, ranging from urbanization to depopulation, further strain their capacity to adapt to climate and environmental change. Moreover, small islands often depend on external financial resources and aid for development and climate change adaptation, with governance structures and historical legacies shaping their

adaptation capabilities.

Despite their vulnerabilities, small islands possess characteristics that could enhance their resilience to climate-related challenges, such as dense social networks, experience in coping with environmental adversity, and traditional knowledge (Ratter & Ratter, 2018).

CI and CI Resilience

Critical Infrastructure (CI) encompasses the essential facilities and systems crucial for the functioning of urban and rural areas, such as railways, roads, tunnels, bridges, power grids, energy sources, electricity networks, telecommunications, water supplies, sewers, etc. (Feofilovs & Romagnoli, 2017). They play a central role in society, especially when facing both technological and natural disasters.

The definition of CI is not universally standardized, as different entities and regions have varying perspectives on what constitutes CI. For instance, the U.S. Department of Homeland Security considers infrastructures critical if their incapacity would significantly impact defense and economic security (U.S Department of Homeland and Security, 2022), while the European Commission identifies CIs as those whose disruption would seriously affect the health, safety, security, or economic well-being of citizens or the functioning of governments in the European Union (EU) (EUR-Lex, 2010).

Despite the lack of a universally accepted definition, all conceptions of CI emphasize its vital role and the potentially severe societal consequences in the event of its disruption. Similarly, the term “resilience” is multidisciplinary and poses challenges in its definition. Originating in mechanics, it initially described an object's capacity to revert to its original form after undergoing external forces without fracturing (Holling, 1973). Over time, it has found broad application across various disciplines including ecology, sociology, psychology, etc. (Bruneau et al., 2003).

When applied to CIs, the concept of resilience emphasizes the ability capacity of a system to widely recover following disasters, even when infrastructure systems experience localized damage due to severe natural or human-induced disruptive occurrences (Ouyang et al., 2019). The concept is also applied to the interdependencies between CIs, recognizing that the failure of one infrastructure can have cascading effects on others (Pal et al., 2023).

CI Assessments and Participatory Approaches

Resilience is often assessed through indicators and variables that affect CIs’ organizational functionalities. They provide a means to assess baseline conditions, measure the effectiveness of interventions, and track resilience progress over time (Bruijn et al., 2019).

An indicator is factual data that can be measured, and its assessment can adopt quantitative, semi-quantitative or qualitative formats. Quantitative approaches offer standardized measures to quantify value across applications and frameworks tailored to specific domains. Semi-quantitative approaches provide numerical descriptions without complex formulas or models, while qualitative methods rely on subjective analyses and judgments, often incorporating insights from surveyed experts or operators (Cantelmi et al., 2021).

Evaluating the current resilience of a system can be accomplished through two main approaches. Firstly, by analyzing how the system responds to an event and measuring the extent of disruption or recovery across various scenarios. For example, Barabadi et al. (2020) examined the resilience of health infrastructure before and after the COVID-19 pandemic, assessing its ability to withstand and recover from the crisis.

Alternatively, resilience can be assessed by identifying the inherent characteristics of the system that promote resilience. This involves pinpointing societal factors and infrastructure qualities that contribute to resilience, such as the 100 Resilience City Framework developed by ARUP (2018). By evaluating the presence of these characteristics, analysts can gauge the system's capacity to adapt and recover from disruptive events.

Participatory processes are particularly valuable in capturing indicators in small island settings, as they facilitate the inclusion of perspectives from potentially marginalized groups into resilience planning and implementation (Bedsted and Gram, 2013). A participatory approach involves actively engaging community members in decision-making processes, ensuring that their perspectives are incorporated into the development of resilience strategies and actions (Jamero et al., 2018).

However, it's essential to recognize that labeling an approach as "participatory" does not guarantee its inclusivity at all scales, as cautioned by Cunningham (2019). This process must be accompanied by accountability and transparency to ensure that responsibility for critical infrastructure (CI) resilience is translated into practice. It

goes beyond mere consultation, emphasizing collaboration and partnership between researchers, policymakers, and local stakeholders.

This approach has been applied across various settings, as demonstrated in Talubo et al. (2022), where a combination of participatory methods was used to identify composite indicators for assessing disaster resilience in an island community.

PROPOSED METHODOLOGY

The approach proposed in this methodology involves examining the system's response to an event, quantifying both the disturbances, impacts, and dependencies, and the subsequent recovery across a specific scenario. The methodology will be employed as part of a 2023-2026 doctoral study program conducted at the University of Wuppertal and the German Aerospace Center, focusing on the East Frisian Islands in Lower Saxony-Germany as a case study. The East Frisian Islands present a pertinent context for this research due to their small island setting, vulnerability to climate change-induced hazards, and reliance on CI for socio-economic activities and community well-being.

Utilizing case studies as a research method are valuable in comprehending how individuals and communities respond to contemporary events and issues (Robson & McCartan, 2016; Yin, 2018). An exploratory approach guides the investigation of these case studies, allowing for a deeper understanding of the factors influencing priorities in the face of climate-related hazards. This approach is particularly suitable when exploring issues beyond the researcher's control, such as the unpredictable nature of climate impacts (Yin, 2018).

The study advocates a stakeholder-led approach, emphasizing the central role of participatory approaches in data collection. These methods are structured to develop in four distinct but interrelated phases, which may at times take place simultaneously:

- On Phase 1, thorough examination of existing literature, documents, reports, and academic publications an initial literature review and documentary analysis are conducted to gain a comprehensive understanding of the contextual factors and distinctive challenges encountered by small island communities, with a specific focus on the case study area.
- Phase 2 brings together stakeholders in participatory workshop(s) conducted in collaboration with local authorities, community representatives, and infrastructure managers. These will serve as interactive platforms for assessing the impacts of disaster disruptions on infrastructure systems, taking into account dependencies and cascade effects.
- On Phase 3 semi-structured interviews are conducted as a complementary approach to further enrich the insights gained from other phases, particularly regarding stakeholders' perceptions and experiences.
- Phase 4 employs an integrated qualitative and/or quantitative analysis based on the findings from the scenario-based impact assessments in order to refine strategies for mitigating disruptions and enhancing CI resilience.

Phase One: Literature Review and Documentary Analysis

The methodology employed in this study encompasses an extensive review of existing literature on disaster impacts, infrastructure resilience assessments, and participatory approaches in small island contexts. This review aims to identify gaps and relevant concepts pertinent to the subject matter, focusing on the specific context and requirements of the small island(s) to be assessed.

To conduct the literature review, a systematic approach is adopted, involving keyword searches, content analysis, and the examination of titles and abstracts to identify relevant literature. This approach ensures a comprehensive understanding of the current state of knowledge in the field, allowing for the identification of key themes, trends, and areas requiring further investigation. The review encompasses a range of sources, including scientific studies, case reports, and institutional documents, focusing on climate change vulnerability and resilience in small island contexts.

In addition to the literature review, a documentary analysis method is employed for the study case(s). This qualitative technique involves the analysis of content within various documents, such as official reports, meeting minutes, newspaper articles, social media posts, and other written or recorded content. Documentary analysis is valuable for gaining deeper insights into the research topic, complementing research efforts (Robson & McCartan, 2016).

The records produced during documentary analysis provide a deeper understanding of the case studies as real-world communities, serving as a vital step before fieldwork begins. Specific key questions addressed include which scenarios, key stakeholders, and elements of infrastructure should be included in the assessment process. An example of potential CI sectors to be considered is presented in Table 1 (Petrakos & Kotzanikolaou, 2019).

Table 1: Example of CI sectors and their respective service/organizations.

CI Sector	Service/Organizations
Transport	- Air/road/train/maritime transport
	- Services and network
Water (supply and disposal)	- Storage, distribution, quality
	- Collection and treatment
Energy (electricity, petroleum, gas, etc.)	- Production, transport and distribution
Health	- Emergency healthcare
	- Hospital care
	- Medical supplies
	- Nursing care
Food	- Agriculture/fishery production
	- Food supply and distribution
Information technologies & media	- Web/cloud services
	- Internet, voice/data communication
	- Media press and broadcasting
Administration	- Government functions (economy, engineering, etc.)
Defense and civil protection	- Crisis management, emergency and rescue services
Tourism	- Touristic infrastructure (property, visitors' sites, recreational services)
	- Sector employment
Housing and land use	- Village urban planning zone
	- Private and public properties
Community and social organizations	

Phase Two: Participatory Workshops

Participatory workshops are conducted on the selected small islands to engage communities in assessing potential impacts and cascading effects on infrastructure using developed scenarios.

Scenarios serve as a crucial tool to address uncertainty, particularly concerning poorly understood, difficult-to-quantify, or unidentified risks. They provide a systematic method for assessing how diverse and complex risks could impact society, essentially evaluating the resilience of systems to potential disruptions (Strong et al., 2020).

During the workshops, collaboration between various stakeholder groups, including community members, municipal representatives, critical infrastructure operators, authorities and organizations with security tasks, is encouraged to address concrete indicators of functionality in crisis events and dependencies on other organizations. This participatory approach promotes dialogue, knowledge exchange, and collective problem-solving (Bizikova et al., 2011; Sheppard et al., 2011), and has also been recorded in the particular context of coastal communities (Simpson et al., 2012). Peer learning is also promoted, as workshops lead to a facilitated exchange of best practices and experiences between participants.

The workshops are structured to commence with an explanation of the workshop's purpose and an introductory keynote addressing key issues faced by small islands during disasters, emphasizing the significance of evaluating their impacts on infrastructure and population.

Then, participants are presented with a range of potential scenarios, covering sudden-onset hazards ranging from

natural occurrences such as floods, coastal erosion, droughts or storms, to human-induced events such as blackouts, disease epidemics or civil conflicts (Strong et al., 2020). These scenarios are discussed among the participants and ranked based on their potential impacts and occurrence probability in their small island context.

In the second part, one scenario is selected for further analysis. Stakeholders identify emerging issues from the selected scenario for their respective facilities and interests, explore mutual dependencies, and support potentials between different organizations. Questions to stakeholders revolve around indicators: variables that affect their organization's functionalities (e.g. number of accommodation facilities or access sea routes into the island at a given time). Questions are exemplified below:

- What indicators are necessary in your organization to ensure its functionality? Give examples in measurable and comprehensive units.
- How can those indicators be impacted in each disaster scenario?
- What dependencies exist with other organizations? What possible impact does the non-conformity of these dependencies have on the infrastructure system and population?
- What challenges do you foresee arising in your organization from each scenario?

The results are collectively discussed, and the points raised by the participants can be listed and placed in diagrams for better visualization of the CIs and their dependencies. After the discussion, a feedback session takes place to gather additional insights and perspectives.

Phase Three: Semi-Structured Interviews

Building upon workshop insights, interviews are conducted with identified actors from the study area(s) to gather valuable insights into various aspects of the island's infrastructure and also to complement the data and results of the other phases.

The semi-structured interview provides consistency in conversations through predefined prompts, while also allowing for unexpected topics of interest to be explored and for clarifications/follow-up questions from participants' answers (Paine, 2015).

These interviews are conducted with experts who possess relevant knowledge or access to such knowledge within their organizational units. The insights provided by these experts offer valuable perspectives on different facets of the island's infrastructure, contributing to a comprehensive understanding of its strengths, weaknesses, and resilience.

Considering the scenario chosen during the workshops, a second part of the interview focuses on what kind of mitigating actions could be implemented by the organization or sector itself or in collaboration with others.

Interview questions and dynamics are flexibly structured to ensure alignment with the research objectives and methodology. This flexibility allows for the exploration of diverse topics related to infrastructure resilience, climate change impacts, and disaster preparedness. It also facilitates the first hand transmission of participant knowledge and expertise, enabling researchers to glean nuanced insights into the challenges and opportunities facing the island's infrastructure.

Phase Four: Data Analysis

Data obtained from phases 1, 2 and 3 can be examined using quantitative or qualitative approaches. The debate over which method to use when studying complex issues is tenuous, as each approach has its own strengths and weaknesses (Matsika et al., 2016).

Decision makers often favor quantitative data for their decision-making processes, especially in analyses like cost-benefit assessments that require numerical values (Matsika et al., 2016). However, qualitative assessments offer valuable context and understanding, complementing quantitative data (Bernroider et al., 2016).

For instance, Van Laere et al. (2017) investigated challenges encountered during disruptions in the payment system using inductive qualitative research methods. Through document analysis, interviews with key sector representatives, and workshops with local and national stakeholders, they developed scenarios and identified resilience challenges for CIs. Their analysis underscored the importance of addressing communicative challenges such as maintaining trust and preventing panic among the public, alongside technical solutions.

However, Fekete & Fiedrich (2018) expressed skepticism about measuring resilience quantitatively due to the complexity of CIs but also cautioned against relying solely on qualitative assessments. They advocated for a

mixed-methods approach, combining quantitative and qualitative dimensions to provide a broader perspective and cater to diverse end users. Münzberg et al. (2017), exemplifies this approach on supporting community resilience through a spatial-temporal vulnerability assessment. By integrating various indicators using the Delphi method and Monte Carlo simulation, they provided decision-makers with a comprehensive understanding of power outage impacts, aiding in resilience-building efforts.

In the context of disaster resilience and CI, the data analysis techniques may involve utilizing quantitative methods to analyze numerical data collected during impact assessments or participatory workshops. This could include statistical analysis to identify patterns or trends in the data.

Qualitative data analysis techniques, on the other hand, may involve thematic analysis of interview transcripts or documentary analysis findings. This qualitative approach allows researchers to explore the nuanced perspectives and experiences of stakeholders, providing rich insights into their perceptions and behaviors.

CONCLUSION

The resilience-focused methodology proposed in this study offers a comprehensive structure for assessing infrastructure resilience in small island environments. By synthesizing findings from literature reviews, documentary analyses, interviews and participatory workshops the methodology aims to capture the complex dynamics of disaster impacts and cascading effects within these vulnerable contexts.

One key feature of the proposed methodology is its emphasis on scenario-based participatory approaches, which enable stakeholders to actively engage in the assessment process and explore various resilience strategies. Through this collaborative approach, the methodology seeks to provide a nuanced understanding of how disasters disrupt infrastructure systems and the subsequent consequences on communities.

Moreover, the discussion surrounding the choice between quantitative and qualitative approaches to analyze the data highlights the flexibility inherent in the proposed methodology. By acknowledging the advantages and drawbacks of each approach, the methodology offers researchers and organizations a practical guide for tailoring their assessment strategies to the unique characteristics of small island settings. Overall, the application of this methodology may generate contributing results for advancing knowledge on infrastructure resilience and supporting efforts for mitigating the impacts of disasters and safeguarding the sustainability of small islands globally.

REFERENCES

Arup Group Limited (2018) City resilience index: understanding and measuring city resilience.

Barabadi, A., Ghiasi, M. H., Nouri Qarahasanlou, A., & Mottahedi, A. A holistic view of health infrastructure resilience before and after COVID-19. ABJS, vol. 8, no. Covid-19 Special Issue (2020).

Bedsted, B., & Gram, S. (2013). Participatory climate change adaptation in Kalundborg, Denmark. *Climate Change Adaptation in Practice: From strategy development to implementation*, 11-23.

Bernroider, E. W., Margiol, S., & Taudes, A. (2016). Towards a General Information Security Management Assessment Framework to Compare Cyber-Security of Critical Infrastructure Organizations. In *Research and Practical Issues of Enterprise Information Systems: 10th IFIP WG 8.9 Working Conference, CONFENIS 2016, Vienna, Austria, December 13–14, 2016, Proceedings 10* (pp. 127-141). Springer International Publishing.

Bizikova, L., Burch, S., Robinson, J., Shaw, A., & Sheppard, S. (2011). Utilizing Participatory Scenario-Based Approaches to Design Proactive Responses to Climate Change in the Face of Uncertainties. In G. Gramelsberger & J. Feichter (Eds.), *Climate Change and Policy: The Calculability of Climate Change and the Challenge of Uncertainty* (pp. 171–190). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-17700-2_8.

Bruijn, K. M. de, Maran, C., Zygnerski, M., Jurado, J., Burzel, A., Jeuken, C., & Obeysekera, J. (2019). Flood Resilience of Critical Infrastructure: Approach and Method Applied to Fort Lauderdale, Florida. *Water*, *11*(3), 517. https://doi.org/10.3390/w110 30517.

Bruneau, M., Chang, S. E., Eguchi, R. T., Lee, G. C., O'Rourke, T. D., Reinhorn, A. M., Shinozuka, M., Tierney, K., Wallace, W. A., & Winterfeldt, D. von (2003). A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities. *Earthquake Spectra*, *19*(4), 733–752. https://doi.org/10.1193/1.1623497.

Cantelmi, R., Di Gravio, G., & Patriarca, R. (2021). Reviewing qualitative research approaches in the context of critical infrastructure resilience. *Environment System and Decisions*, *41*(3), 341–376. https://doi.org/10.1007/s10669-020-09795-8.

Cunningham, F. (2019). *Adaptation to the impacts of climate change in small island communities: an analysis of Scottish case studies* (Doctoral dissertation, University of St Andrews).

EUR-Lex, Critical infrastructure protection, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=legissum%3Al33259, 2010 (accessed 05 Jun. 2023).

Fekete, A., & Fiedrich, F. (Eds.). (2018). *The Urban Book Series*. *Urban Disaster Resilience and Security: Addressing Risks in Societies* (1st ed. 2018). Springer International Publishing; Imprint: Springer.

Feofilovs, M., & Romagnoli, F. (2017). Resilience of critical infrastructures: probabilistic case study of a district heating pipeline network in municipality of Latvia. *1876-6102*, *128*, 17–23. https://doi.org/10.1016/j.egypro.2017.09.007.

Hiwasaki, L., Luna, E., Syamsidik, & Marçal, J. A. (2015). Local and indigenous knowledge on climate-related hazards of coastal and small island communities in Southeast Asia. *Climatic Change*, *128*, 35-56.

Holding, S., Allen, D. M., Foster, S., Hsieh, A., Larocque, I., Klassen, J., & Van Pelt, S. C. (2016). Groundwater vulnerability on small islands. *Nature Climate Change*, *6*(12), 1100-1103.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual review of ecology and systematics*, *4*(1), 1-23.

Jamero, M. L., Onuki, M., Esteban, M., & Tan, N. (2018). Community-based adaptation in low-lying islands in the Philippines: Challenges and lessons learned. *Regional Environmental Change*, *18*(8), 2249 – 2260. https://doi.org/10.1007/s10113-018-1332-8.

Kelman, I. (2010). Hearing local voices from Small Island Developing States for climate change. *Local Environment*, *15*(7), 605–619. https://doi.org/10.1080/1354 9839.2010.498812.

Kröger, W., & Zio, E. (2011). Conceptual Frameworks for Vulnerability Assessment. In W. Kröger, E. Zio, & M. Schläpfer (Eds.), *Vulnerable systems* (pp. 55–64). Springer. https://doi.org/10.1007/978-0-85729-655-9_5.

Labaka, L., Comes, T., Hernantes, J., Sarriegi, J. M., & Gonzalez, J. J. (2014). Implementation Methodology of the Resilience Framework. In *2014 47th Hawaii International Conference on System Sciences.* IEEE. https://doi.org/10.1109/hicss.2014.26.

Matsika, E., O'Neill, C., Battista, U., Khosravi, M., Laporte, A. d. S., & Munoz, E. (2016). Development of Risk Assessment Specifications for Analysing Terrorist Attacks Vulnerability on Metro and Light Rail Systems.

2352-1465, *14*, 1345–1354. https://doi.org/10.1016/j.trpro.2016.05.207.

Moser, S. C., Jeffress Williams, S., & Boesch, D. F. (2012). Wicked Challenges at Land's End: Managing Coastal Vulnerability Under Climate Change. *Annual Review of Environment and Resources*, *37*(1), 51–78. https://doi.org/10.1146/annurev-environ-021611-135158.

Münzberg, T., Wiens, M., & Schultmann, F. (2017). A spatial-temporal vulnerability assessment to support the building of community resilience against power outage impacts. *Technological Forecasting and Social Change*, *121*, 99–118. https://doi.org/10.1016/j.techfore.2016.11.027.

Mycoo, M., Wairiu, M., Campbell, D., Duvat, V., Golbuu, Y., Maharaj, S., Nalau, J., Nunn, P., Pinnegar, J., & Warrick, O. (2022). Small islands. *IPCC WGII Sixth Assessment Report.*

Nurse, L. A., McLean, R. F., Agard, J., Briguglio, L. P., Duvat-Magnan, V., Pelesikoti, N., ... & Webb, A. (2014). Small islands. *Climate change 2014: Impacts, adaptation, and vulnerability. Part B: Regional aspects. Contribution of working group II to the fifth assessment report of the intergovernmental panel on climate change*, pp-1613-1654. https://doi.org/10.2134/jeq2008.0015br.

Ouyang, M., Liu, C., & Xu, M. (2019). Value of resilience-based solutions on critical infrastructure protection: Comparing with robustness-based solutions. *Reliability engineering & system safety*, *190*, 106506.

Paine, G. (2015). A Pattern-Generating Tool for Use in Semi-Structured Interviews. *The Qualitative Report.* Advance online publication. https://doi.org/10.46743/ 2160-3715/2015.2123.

Pal, I., Kumar, A., & Mukhopadhyay, A. (2023). Risks to Coastal Critical Infrastructure from Climate Change. *Annual Review of Environment and Resources*, *48*(1), 681–712. https://doi.org/10.1146/annurev-environ-112320-101903.

Petrakos, N., & Kotzanikolaou, P. (2019). Methodologies and Strategies for Critical Infrastructure Protection. *Critical Infrastructure Security and Resilience*, 17–33. https://doi.org/10.1007/978-3-030-00024-0_2.

Ratter, B. M., & Ratter, B. M. (2018). Island vulnerability and resilience. *Geography of small islands: Outposts of globalisation*, 173-199. https://doi.org/10.1007/978-3-319-63869-0_6.

Petzold, J., & Magnan, A. K. (2019). Climate change: thinking small islands beyond Small Island Developing States (SIDS). *Climatic change*, 152(1), 145-165.

Pörtner, H. O., Roberts, D., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., Rama-Phd, B., Belling, D., Dieck, W., Götze, S., Kersher, T., Mangele, P., Maus, B., Mühle, A., & Weyer, N. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* https://doi.org/10.1017/9781009325844.

Rampengan, M. M. F., Boedhihartono, A. K., Law, L., Gaillard, J. C., & Sayer, J. (2014). Capacities in Facing Natural Hazards: A Small Island Perspective. *International Journal of Disaster Risk Science*, *5*(4), 247–264. https://doi.org/10.1007/s13753-014-0031-4.

Robson, C., & McCartan, K. (2016). Real World Research: A Resource for Users of Social Research Methods in Applied Settings. 4th ed. John Wiley and Sons Ltd.; West Sussex, UK: 2016.

Roy, P., Pal, S. C., Chakrabortty, R., Chowdhuri, I., Saha, A., & Shit, M. (2023). Effects of climate change and sea-level rise on coastal habitat: Vulnerability assessment, adaptation strategies and policy recommendations. *Journal of Environmental Management*, *330*, 117187. https://doi.org/10.1016/j.jenvman.2022.117187.

Sheppard, S. R., Shaw, A., Flanders, D., Burch, S., Wiek, A., Carmichael, J., Robinson, J., & Cohen, S. (2011). Future visioning of local climate change: A framework for community engagement and planning with scenarios and visualisation. *0016-3287*, *43*(4), 400–412. https://doi.org/10.1016/j.futures.2011.01.009.

Simpson, M., Clarke, J., Scott, D., New, M., Karmalkar, A., Day, O., Taylor, M., Gossling, S., Wilson, M., Chadee, D., Stager, H., Waithe, R., Stewart, A., Georges, J., Hutchinson, N., Fields, N., Sim, R., Rutty, M., Matthews, L., & Agosta G'meiner, A. (2012). *THE CARIBSAVE CLIMATE CHANGE RISK ATLAS (CCCRA) - Climate Change Risk Profile for the Dominican Republic.*

Strong, K., Carpenter, O., & Ralph, D. (2020). Scenario best practices: developing scenarios for disaster risk reduction. *Cambridge Centre for Risk Studies at the University of Cambridge*, 12–15.

Talubo, J. (2022). *Assessing small island socio-ecological resilience for disaster risk and recovery planning in the Philippines* (Doctoral dissertation, University of Surrey).

U.S Department of Homeland and Security, 2022. Critical Infrastructure Security & Resilience Research (CISRR), Fact Sheet https://www.dhs.gov/sites/default/files/2023-06/23_0614_st_Critical_Infrastructure_Security_Resilience_Research.pdf (accessed 12 Aug. 2023).

Van Laere, J., Berggren, P., Gustavsson, P., Ibrahim, O., Johansson, B., Larsson, A., Lindqwister, T., Olsson, L., & Wiberg, C. (2017). Challenges for critical infrastructure resilience: Cascading effects of payment system disruptions. In (pp. 281–292). ISCRAM. https://www.diva-portal.org/smash/record.jsf?pid= diva2:1094917.

Yin, R. K. (2018). Case study research and applications (Vol. 6). Thousand Oaks, CA: Sage.