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Climate, Disaster and Risk

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Climate, disaster and risk: introduction

Simon Goldhill and Georgie Fitzgibbon

Abstract: This special issue focuses on the intersections of climate, disasters, and development. The research presented here is designed to facilitate climate-resilient decision-making, and promote sustainable development by maximising the beneficial impacts of responses to climate change and minimising negative impacts across the full spectrum of geographies and sectors that are potentially affected by the changing climate.

Keywords: Disaster, Risk, Sustainable Development, Logistics, Shelter, Vulnerability, Resilience, Infrastructure

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This special issue focuses on the intersections of climate, disasters and development. The research presented here is designed to facilitate climate-resilient decision-making, and promote sustainable development by maximising the beneficial impacts of responses to climate change and minimising negative impacts across the full spectrum of geographies and sectors that are potentially affected by the changing climate.

In the first article John Twigg (2021) explores the evolution of shelter 'self-recovery'. Providing adequate shelter after disasters is often a huge challenge to humanitarian agencies, whose interventions may reach only a small proportion of affected households. To overcome this problem, the international humanitarian shelter sector is increasingly adopting what is called a 'self-recovery' approach that gives much greater choice and agency to disaster-affected households regarding their recovery pathways. This article reviews the concept of 'self-recovery', its application to housing reconstruction after disasters and the factors influencing its recent rise to prominence in humanitarian policy and practice. The article draws on academic studies, evidence generated by humanitarian agencies and the author's involvement as observer and participant in recent self-recovery initiatives.

The next article examines two experiences that have aimed to incorporate vulnerability concerns into the planning and optimisation of humanitarian logistics operations. Douglas Alem (2021) argues that natural disasters and the vulnerability of a population go hand in hand. We cannot understand the level of a disaster without grasping the extent of people's vulnerability. But how can we ensure that humanitarian assistance is targeted at people's vulnerability when the lack of resources makes it impossible to support all those that need it? This study thus contributes to this line of research by enhancing our understanding of how we can 'put the reality of the most vulnerable people first'. The first example relies on a very popular composite indicator called Social Vulnerability Index (SoVI) to build enhanced response capacity in more vulnerable areas. The second example is built upon a poverty measure called Foster-Greer-Thorbecke (FGT) to identify the groups that potentially need the most relief aid supply and to help devising allocation plans in compliance with people's income. These two models reveal that in most cases targeting more vulnerable areas increases their level of access to relief aid goods without greatly compromising the relief service levels of less vulnerable areas.

Continuing in this vein, Peter Sammonds, Mohammad Shamsudduha and Bayes Ahmed (2021) discuss the lessons that can be learned from Bangladesh's journey towards resilience. Globally, disasters from natural and anthropogenic hazards or humanitarian crises can reverse development gains and weaken resilience. In recent years, some countries have made significant progress towards building resilience to disaster risks, including those driven by the climate crisis. Bangladesh is a leading example as it is one of the most vulnerable countries because of its particular intense and multifaceted hazard risks from climate change. Today, however, the scale of loss of human life from both rapid and slow-onset disasters (e.g., cyclone, flood and drought) is significantly lower than in the 1970s. This remarkable achievement was made possible by independence and the government's proactive investment in development and societal changes through education, technologies, and reduction in poverty and inequalities. However, the climate crisis is threatening these development and disaster risk reduction gains. In addition, disaster displacement is a major challenge. The COVID-19 pandemic has unveiled both strengths and weaknesses in our societies. This article argues that disaster management plans need to adapt to the climate crisis and human displacement and reduce migrants' vulnerability while responding to infectious disease transmission.

In the penultimate article Robin Coningham and Lisa Lucero (2021) consider lessons that could be learned from past disasters. Narratives of lost cities and the exploration of ruins have captivated scholars and travellers for hundreds of years with explanations for their demise ranging from invasions to cataclysmic environmental events. This article explores three case studies to consider the impact of climate change, disaster and risk on urban infrastructure in the past, as well as to reflect on potential lessons of adaptation and resilience for modern cities and their inhabitants. The first examines the degree to which historic urban infrastructure can tell us about seismic adaptation in pre-modern Nepal, as well as recognising the increasing challenges to vernacular architecture from climate change. The second, focusing on Sri Lanka's Medieval cities in the North Central Province, examines the intricate relationship between the ancient city of Anuradhapura and its artificial hydraulic landscape, a relationship which saw resilience defeated by irreversibly engineered adaptation. The final example is drawn from the experience of another tropical society on the other side of the globe, the low-density urban forms of the Classic Maya of Central America, which offers different yet relevant insights into alternate urban lifeways, both ancient and contemporary. Focusing on issues of successful and unsuccessful adaptations in urban settings over an archaeological time range and evaluating how archaeologists and historians have explored and presented this evidence, we conclude by considering how archaeology and archaeologists can also play a greater role in future sustainable urban planning.

The final article is based on an 18-month British Academy funded project, which focused on the Canary Islands, in order to clarify the condition of documentation with regard to connections with West Africa, primarily with Senegal, which is described as the main origin of the migrants to the Canary Islands. With the collaboration of Italian and Spanish academics and the utilisation of Canarian data, Caroline Wilkinson and Maria Castaneyra-Ruiz (2021) interrogate the challenges associated with the identification of migrant victims off the coast of the Canary Islands through fostered networks in the Canary Islands and Senegal. Finally, the report presents craniofacial depiction/analysis as an alternative biological and biometric tool for Migrant Disaster

Victim Identification (MDVI). This project did not involve the implementation of migrant identification, but this will hopefully be achieved through follow-up projects. The report ends with a summary of the current status and provides recommendations for future MDVI.

This issue forms part of the British Academy's COP26 series which aims to raise awareness of the importance of the humanities and the social sciences in understanding the complex human and social dimensions to environmental challenges and their solutions. The authors are drawn from a range of Academy programmes, including *Cities and Infrastructures*, which funds interdisciplinary research projects that address the challenge of creating and maintaining sustainable and resilient cities, with the aim of informing relevant policies and interventions in developing countries, *BA/Leverhulme Small Research Grants*, which support primary research across the humanities and social sciences, and *Knowledge Frontiers*, which aims to enable different communities of knowledge and practice to illustrate the significant added value of international and interdisciplinary collaboration.

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The evolution of shelter 'self-recovery': adapting thinking and practice for post-disaster resilience

John Twigg

Abstract: Providing adequate shelter after disasters is often a huge challenge to humanitarian agencies, whose interventions may reach only a small proportion of affected households. To overcome this problem, the international humanitarian shelter sector is increasingly adopting what is called a 'self-recovery' approach that gives much greater choice and agency to disaster-affected households regarding their recovery pathways. This article reviews the concept of 'self-recovery', its application to housing reconstruction after disasters and the factors influencing its recent rise to prominence in humanitarian policy and practice. The article draws on academic studies, evidence generated by humanitarian agencies and the author's involvement as observer and participant in recent self-recovery initiatives.

Keywords: disaster, humanitarian, shelter, recovery, reconstruction, agency.

Note on the author: Dr John Twigg is an independent researcher, an Honorary Professor at University College London, and a co-editor of the journal *Disasters*. He has worked in the field of disasters, risk and resilience for more than 20 years, in the academic, NGO and consultancy sectors. His recent publications include: Twigg, J. *et al.*, *Accountable Governance and Resilient Development: Thinking and Acting for Transformative Change* (Oxfam International, 2020); Twigg, J. and Mosel, I., 'Emergent Groups and Spontaneous Volunteers in Urban Disaster Response' (*Environment & Urbanization*, 29(2): 443–458, 2017); and Twigg, J., *Disaster Risk Reduction* (London: Humanitarian Practice Network, Good Practice Review no. 9, 2nd edition, 2015).

Introduction

Building collapse is a major cause of injury, trauma and death in disasters. Between 2005 and 2018 more than 3.3 million houses were damaged and over 2.7 million destroyed globally by natural hazards and conflict.[1] However, providing adequate shelter after disasters is 'one of the most intractable problems in international humanitarian response'[2] and a repeated challenge to post-disaster response and recovery. Humanitarian agencies' interventions to repair and rebuild houses reach a relatively small proportion of those affected.[3] Rebuilding a home is an immediate priority for disaster-affected households, but post-disaster assistance often takes time to arrive, and rebuilding destroyed and damaged housing can take many years.[4]

This article discusses the evolution of an approach commonly referred to as shelter 'self-recovery' that aims to support more rapid, effective and inclusive shelter reconstruction after disasters. The approach, which has gained considerable momentum in the past few years, has engaged researchers and humanitarian practitioners in an ongoing dialogue, seeking to understand what self-recovery is and how best to support it through policies and programmes. The aim of the article is to review and reflect upon the evolution of self-recovery: how the concept and practice have been developed and applied in the international humanitarian shelter sector, and the factors influencing this rise to prominence. Better understanding of these processes should assist humanitarian shelter practitioners, policy makers and donors to improve practice and target their support more effectively. I have drawn on academic writing on disasters and reconstruction, the numerous evaluations, reports and other data generated by humanitarian agencies on their shelter interventions, and my own views from involvement as an observer and participant in self-recovery initiatives since 2016.

Humanitarian shelter intervention

Shelter serves many functions before, during and following disasters. It provides a place to store belongings, protection against the elements (cold, heat, wind and rain), emotional security and privacy. It is a staging point for future action, including salvage and reconstruction, and an address for delivery of services such as food and medicine. It also demonstrates a territorial claim through ownership and occupancy rights.[5]

1 Sharma (2018).

2 Ashdown *et al.* (2011: 25).

3 Parrack *et al.* (2014); Maynard *et al.* (2017); Miranda Morel (2018).

4 Davis & Alexander (2016).

5 Davis *et al.* (2015).

House-building in low-income countries and communities is often an informal process driven by householders and community groups.[6] In development practice, it has long been understood that assisting organisations should support such processes rather than just providing houses. This involves identifying critical interventions regarding access to, and management of, land, services, finance and technical assistance. Humanitarian shelter policy and practice have been slower to adopt such supporting approaches or to acknowledge the incremental nature of the housing process, the multiplicity of shelter pathways taken by disaster-affected families and the importance of owner-driven approaches to housing reconstruction.[7]

Self-recovery can be seen as the latest stage in the evolution of thinking and practice about effective, appropriate shelter provision after disasters. It is an extension of much earlier ideas and approaches to development and disaster response (for example, community participation and owner-led reconstruction). Ian Davis' book *Shelter after Disaster* (1978)—the first serious critique of top-down, technocratic approaches to emergency shelter provision and reconstruction—argued against imposed and often impractical designs for rebuilding houses that were alien to their inhabitants' social, economic and cultural needs. He recognised that 'people build their homes in response to their *everyday* needs—their occupations, their wealth, their traditional construction techniques and their cultural patterns'; and he observed that house reconstruction 'usually starts immediately, and takes place irrespective of government plans for relocation etc'. Four years later, Davis and colleagues placed emphasis on shelter needs from the standpoint of the survivor receiving aid, pointing out that self-help and participation by local households, builders and craftsmen were key elements in reconstruction: 'The primary resource in the provision of post-disaster shelter is the grass-roots motivation of survivors, their friends and families.'[8]

The basic contours of this discussion have remained similar in the decades since *Shelter after Disaster* was published. There has been consistent and widespread criticism of the persistence of 'donor-driven' housing reconstruction: supply-driven, agency approaches that build and deliver houses without listening to disaster-affected households' views or understanding their needs and priorities. This often leads to inappropriate designs, building materials and even locations. Counter-arguments have made a case for more developmental, 'people-centred' or 'owner-driven' reconstruction that responds to demand, on the grounds that most people build or manage their own house construction in any case, and because the participatory process is itself empowering.[9]

6 Schilderman (2010).

7 Maynard *et al.* (2017).

8 Davis (1978: 6, 30); Davis *et al.* (1982: 3).

9 Davis and Alexander (2016).

In particular, the experiences of the widespread destruction caused by the 2004 Indian Ocean tsunami in several Asian countries revealed the inadequacy of conventional, formal reconstruction approaches to meet housing needs, and stimulated greater uptake of more owner-driven, people-centred, participatory processes. The first of the 10 'Key Propositions for Building Back Better' set out by the UN Secretary General's Special Envoy for Disaster Recovery (former US President William J. Clinton) in his report on lessons learned from the tsunami was that 'Governments, donors, and aid agencies must recognize that families and communities drive their own recovery'.[10]

Yet in practice many reconstruction projects that are said to be 'owner-driven' continue to restrict owners' agency. Donors, humanitarian organisations and governments continue to direct building strategy and choose or develop designs, while householders are only involved in the act of construction.[11] The principles that are widely repeated in formal guidance on shelter recovery and reconstruction, based on many years of lessons learned, often appear to have little influence on organisational practice. In addition, community participation in formal recovery initiatives can be a time- and resource-consuming process. For example, in Aceh, Indonesia, after the 2004 tsunami, some international NGOs reported that planning and preparation for housing reconstruction projects took 6–12 months: this included selection of eligible households, plot mapping, spatial planning, obtaining agreements from the community, government and religious leaders, and dealing with appeals. Similarly, in Alto Mayo, Peru, following an earthquake in 1990, a participatory process with communities to plan reconstruction and design houses lasted for six months.[12] Community and participatory approaches can also be undermined by the pressure to rebuild quickly, particularly where there has been large-scale destruction.[13]

Nevertheless, the 2004 tsunami led to growing interest in more holistic approaches to reconstruction and recovery that address the physical, social and economic conditions required to achieve greater resilience.[14] Recent research and guidance puts more emphasis on the complexity and evolutionary nature of recovery processes, innovation and adaptation, the involvement and roles of new or different actors, interactions across different levels, and the voices of disaster-affected communities.[15] Supporting shelter self-recovery is one way for humanitarian agencies to respond and adapt to these perspectives. The international humanitarian shelter sector is increasingly

[10] Clinton (2006); Lyons *et al.* (2010).

[11] Schilderman (2010); Da Silva and Batchelor (2010).

[12] Schilderman (1993); Da Silva (2010); Lyons *et al.* (2010).

[13] Da Silva and Batchelor (2010).

[14] Kennedy *et al.* (2008); Mannakkara and Wilkinson (2013).

[15] Few *et al.* (2014); McManus *et al.* (2015); Becker and Reusser (2016); Blackman *et al.* (2017).

moving away from providing housing and towards providing assistance that supports beneficiaries' own shelter self-recovery actions.[16]

Defining self-recovery

In disaster contexts, the term 'recovery' is broad and open to different approaches and interpretations. It is applied mostly to the physical (reconstruction of houses and infrastructure) and economic (restoring livelihoods and businesses) aspects of disasters, but is also used to refer to post-disaster social and cultural life, physical and mental health, institutional change, power relationships and environmental renewal. Other terms often used synonymously with recovery are: rebuilding, reconstruction, rehabilitation and restoration. In addition, recovery is generally an uneven, long-term process of transition with no clear end point.[17]

The term 'self-recovery' is ambiguous. At first sight it appears self-explanatory and it is popular among humanitarian shelter practitioners, but not always used consistently. It is still not well understood as a reconstruction process.[18] In fact, it encompasses a wide range of activities and processes.[19] At one end of this range, it refers to the unassisted self-repair and self-reconstruction which householders engage in,[20] but self-recovery is so broad and open as a concept that, inevitably, researchers and practitioners have approached it in different ways, focusing on different aspects. From a household's point of view:

> *Self-recovery can imply self-build, but can also include rebuilding using the local informal building sector. Either way, households rebuild or repair damaged or destroyed homes using their own assets. Assets can be savings, materials (salvaged, donated or owned), social and community assets, local skills and labour. Increasingly, remittances from family members living abroad are an important asset.*[21]

Humanitarian programmes described as providing support for shelter self-recovery typically include a combination of: material assistance (including construction materials, tools, salvaging and reuse of debris); financial assistance (cash or vouchers) for the purchase of construction materials, tools or labour; and technical assistance (training, on-site monitoring and the provision of guidance through guidelines/mass communications).[22]

16 Schilderman (2004); Davidson *et al.* (2007); Twigg *et al.* (2017).

17 Davis and Alexander (2016).

18 Schofield and Miranda Morel (2017); Harriss *et al.* (2020).

19 Twigg *et al.* (2017); Harriss *et al.* (2020).

20 Parrack *et al.* (2014).

21 Parrack *et al.* (2014: 47).

22 Maynard *et al.* (2017).

Although post-disaster shelter programmes may describe themselves as supporting 'self-recovery' (or use similar terms signifying beneficiary ownership of the shelter process), this does not necessarily mean that a shelter programme has truly enabled homeowners to recover by themselves. The distinction between 'self-recovery' and similar terms and approaches in post-disaster shelter discourse (e.g. owner-driven, community-based, informal, user-built) is similarly blurred. Community involvement in post-disaster housing projects comprises a variety of possibilities for participation, ranging from providing manual labour to long-range decision-making.[23] Similarly, self-recovery may comprise different degrees and types of support from family and community members, and local and formal organisations. A decision to support self-recovery does not preclude complementary forms of shelter assistance such as temporary shelters and provision of cash and rental support.[24]

Agencies and researchers have tended to focus on self-recovery through shelter or livelihoods interventions; other self-recovery pathways may exist, but these are not usually examined or understood.[25] In practice, defining a shelter reconstruction process as one of 'self-recovery' is often based on deciding 'to what degree the process was driven by beneficiaries'.[26] Although this definitional ambiguity has its drawbacks, 'self-recovery' has value as an umbrella term that enables humanitarians to engage with the broad principle.

The key issue here is the degree to which disaster-affected households are actors and decision-makers regarding the reconstruction of their homes. Where there is no external support, householders are in charge of their 'self-recovery'. Where they are supported by formal shelter programmes, they may have differing degrees of ownership and agency in the reconstruction process. However, the expected outcomes of reconstruction approaches are broadly similar: disaster-affected households live in adequate shelters; they can carry out essential household and livelihood activities; they recover socially and economically; and this contributes to their long-term physical, social, economic and environmental recovery and resilience.[27]

The main point of departure for self-recovery from other participatory and owner-driven approaches is said to be its emphasis on giving much greater choice and agency to disaster-affected households regarding their own recovery pathways. In effect, this recognises that self-recovery is an inevitable process, whether or not external assistance is also provided.[28] This means shifting from the 'confined choice' that humanitarian and donor agencies tend to offer (e.g. from an approved range of

23 Davidson *et al.* (2007); Opdyke *et al.* (2019).

24 Twigg *et al.* (2017); Schofield *et al.* (2019).

25 Schofield and Miranda Morel (2017).

26 Harriss *et al.* (2020: 322).

27 Maynard *et al.* (2017).

28 Schofield and Flinn (2018).

building designs and materials) to giving households much more freedom of choice regarding their priority needs (e.g. choosing between material and technical support for reconstruction, or financial backing to restart livelihood activities). The latter approach also implies greater investment in community mobilisation, knowledge exchange, training and supervision, with agencies putting more emphasis on 'accompaniment' to self-recovery instead of directing reconstruction programmes.[29]

The term 'self-recovery' has appeared almost exclusively in post-disaster *shelter* discourse, which sees the house or home as the focal point for other forms of recovery (economic/livelihood, social, cultural and psychosocial). In practice, however, the application of 'self-recovery' mainly to the physical and structural aspects of shelter has tended to separate physical reconstruction from other connected and complementary aspects of household and community recovery.[30]

Rationale for self-recovery

The case for supporting self-recovery is straightforward and pragmatic. The scale of post-disaster shelter need is often beyond the response capacity of humanitarian organisations.[31] This inevitably leads to growing emphasis on supporting 'self-recovery' and other owner-driven models of shelter and housing reconstruction.[32] Self-recovery is seen as a means of empowering communities to take charge of their own recovery. It enables cost-effective reconstruction of shelter at scale. Shelter programmes that support households to repair and rebuild their own homes reach a much greater percentage of disaster-affected populations, as per-dwelling costs are considerably lower, especially where provision of building materials and cash is based on an analysis of needs, capacities and local markets, and coupled with strong community engagement as well as technical assistance. While this support does not provide fully engineered buildings, it supports households to build stronger, often larger, houses that are tailored to their needs and resources. Householders learn safer construction techniques and display a strong sense of ownership and pride in the process and the product.[33]

Obtaining reliable data on self-recovery in rapidly changing humanitarian environments is very challenging. There are significant gaps in information about shelter interventions, their coverage and quality; and the information available makes it very difficult to judge how responses contribute to the recovery of households. Nevertheless, there are strong indications that international aid agency support after major disasters

[29] Twigg *et al.* (2017).

[30] Flinn and Echegaray (2016); Newby *et al.* (undated).

[31] Davis (2011).

[32] Maynard *et al.* (2017).

[33] Flinn and Echegaray (2016); Flinn *et al.* (2017); Harriss *et al.* (2020).

provides only a small proportion of housing needs.[34] Inevitably, most houses are repaired or rebuilt by families themselves, using their own assets, which include savings, building materials (salvaged, donated or owned), social and community capital, local skills and labour, and remittances from family members living elsewhere.[35] Self-recovery in post-disaster shelter 'is not the exception but the norm … the majority of affected families will inevitably rebuild their homes themselves, using their own resources', which usually leads to adopting 'the same bad building practice that caused their home to be damaged in the first place'.[36] The clear implication for humanitarian practice is that aid agencies must reposition themselves as advisers and facilitators of shelter assistance, putting more emphasis on communicating and facilitating rebuilding for safety.[37]

Self-recovery's trajectory

As a term and an approach, 'self-recovery' has taken off rapidly in humanitarian discourse and programming. Its use with regard to shelter and settlements originated relatively recently, in responses to cyclones Sidr (Bangladesh, 2007) and Nargis (Myanmar, 2008), earthquakes in Indonesia (2009) and flooding in Pakistan (2011). The international response to Typhoon Haiyan (Philippines) in 2013 is said to be the first major humanitarian shelter initiative to identify the provision of support for shelter self-recovery as a strategic objective. It has subsequently been a strategic objective in many other humanitarian post-disaster shelter responses.[38]

The 2014 paper by Parrack *et al.*, 'Getting the Message across for Safer Self-recovery in Post-disaster Shelter',[39] is said to be the first use and discussion of 'self-recovery' in the literature with regard to humanitarian shelter and settlements.[40] That literature has since grown rapidly. The UK Department for International Development-funded Humanitarian Evidence Programme commissioned an evidence synthesis on self-recovery in 2016[41]—the most systematic study of the subject to date—and a more recent evidence review has evaluated the state of knowledge about the intersection between supporting shelter self-recovery and building back safer.[42] Multi-disciplinary field research, which is discussed below, has investigated self-recovery processes in Nepal and the Philippines.[43]

34 Parrack *et al.* (2014); Maynard *et al.* (2017); Miranda Morel (2018).
35 Parrack *et al.* (2014).
36 Parrack *et al.* (2014: 47).
37 Parrack *et al.* (2014); Harriss *et al.* (2020).
38 Maynard *et al.* (2017); Harriss *et al.* (2020).
39 Parrack *et al.* (2014).
40 Maynard *et al.* (2017).
41 Maynard *et al.* (2017).
42 Harriss *et al.* (2020).
43 Twigg *et al.* (2017); Schofield *et al.* (2019).

Self-recovery has been the focus of in-country workshops in several countries and the subject of presentations and discussions at international conferences.[44] These are generally believed to have been influential in raising the profile of the topic, improving knowledge and understanding, and expanding the scope of enquiries and discussions. The 'Promoting Safer Building' initiative (2016–17, discussed below) rapidly attracted a large informal network of people from humanitarian and development organisations, grassroots organisations, government and policy institutions, academic and scientific institutions, and the private sector, who engaged with the project in one way or another.[45]

In 2017, self-recovery received global institutional backing when it was adopted as a working group of the Inter-Agency Standing Committee (IASC) Global Shelter Cluster as part of its 2018–2022 Strategy.[46] The issue was also identified as a priority research topic for the humanitarian shelter and settlements sector in a recent Delphi survey of expert informants.[47]

Some of the impetus for this interest in self-recovery may have come from the 2016 Istanbul World Humanitarian Summit's emphasis on supporting local actors in disaster response and recovery, with the UN Secretary General stating that humanitarian action should be 'as local as possible, as international as necessary'. The so-called 'grand bargain' launched during the summit and the 'localisation' agenda that followed have seen international donor and operational agencies committing to greater support for local humanitarian action.[48]

[44] Notably presentations at several international events held in 2017: biennial UN Global Forum on Disaster Risk Reduction, Cancun, Mexico; 3rd International Urban Sustainability and Resilience Conference, London, UK; 8th i-Rec Conference, Toronto, Canada; Global Facility for Disaster Risk Reduction, 3rd World Reconstruction Conference, Brussels, Belgium; international conference on 'Promoting safer building and supporting self-recovery', London, UK.

[45] CARE International UK (2017).

[46] Global Shelter Cluster (2018). The Inter-Agency Standing Committee (IASC) is an inter-agency forum for coordination, policy development and decision-making involving key UN and non-UN humanitarian partners. The Global Shelter Cluster (GSC) is an IASC coordination mechanism that enables better co-ordination among all shelter actors, including local and national governments. The GSC is a public platform with 44 partners, co-chaired by the International Federation of Red Cross and Red Crescent Societies (IFRC) and the United Nations High Commissioner for Refugees (UNHCR).

[47] Opdyke *et al.* (2018).

[48] Barbelet (2018).

Understanding self-recovery through research

> *Humanitarian action is the opposite of science. Scientists make conclusions when they have complete data. We make conclusions and decisions without complete data.*[49] *(Speaker from international humanitarian agency at self-recovery conference, London, July 2017)*

As self-recovery began to attract more interest from humanitarians, it became clear that there were limitations in agencies' knowledge and understanding of it. They rely heavily on evaluations and reports on agency interventions, but knew little about self-recovery processes outside this scope. Empirical research was needed. Coincidentally, research funding opportunities became available through the UK Government's Global Challenges Research Fund, set up in 2015 to support cutting-edge research addressing challenges in developing countries.[50] Grants from the Natural Environment Research Council (2016–17) and the British Academy (2018–19) supported field studies of self-recovery after disasters in Nepal (Gorkha earthquake, 2015) and Philippines (typhoons Haiyan, 2013, and Haima, 2016).[51] The first study, 'Promoting safer building—using science, technology, communication and humanitarian practice to support family and community self-recovery', looked at self-recovery in rural and some peri-urban contexts in the two countries; the second focused on urban locations.[52] These projects were multi-disciplinary collaborations of social scientists, geoscientists, structural engineers and humanitarian practitioners. They sought to understand how individual households and communities recover from disasters, what 'recovery' consists of for disaster-affected people, the strategies adopted by households and communities to self-recover, the roles and influence of formal organisations on the self-recovery process, and interventions or conditions that support safer self-recovery.

Researchers investigated household self-recovery trajectories and the wide range of technical, environmental, institutional and socio-economic factors that influenced them, as well as looking at how safer construction practices could be adopted and implemented more effectively. The field research combined methods used in qualitative social science (transect walks, focus groups, semi-structured interviews, timeline mapping), structural engineering and architecture (building surveys), and geosciences (geological and geomorphological surveys). Meetings were also held with representatives of key institutions at national level. External validation was provided by expert workshops in Manila and

[49] CARE International UK (2017: 12).

[50] www.ukri.org/research/global-challenges-research-fund/

[51] 'Promoting safer building—using science, technology, communication and humanitarian practice to support family and community self-recovery' (2016–17) funded by the UK Natural Environment Research Council (ref. NE/P016200/1) and the CARE UK Investment Fund; 'Safer self-recovery: promoting resilient urban reconstruction after disasters' (2018–19) funded by the British Academy (ref. CI170172).

[52] Twigg *et al.* (2017); Schofield *et al.* (2019).

Kathmandu to discuss initial research findings with key stakeholders, including local, national and international humanitarian organisations and donors. Additional feedback came from the project's advisory group, which held regular meetings, and from an international conference of researchers and practitioners in London in July 2017.[53]

The field research methodology was novel and experimental. Despite a common research topic and a genuine commitment to multi-disciplinary working, not all of the team members were comfortable with the approach, and some implicit assumptions and biases remained largely hidden until the writing up of the data. This was particularly true for the first project; and planning for the second project revealed a clear desire among some researchers to draw back into their specialist areas of expertise. Nevertheless, the field research was pivotal in expanding understanding of shelter self-recovery and revealing its complexity, providing new insights into household decision-making and its consequences for future resilience. This evidence also brought attention to the issue, created momentum and supported further growth of a community of practice, paving the way for more empirical research.

Disaster-affected households face many significant environmental, institutional, financial and social challenges: obtaining material and financial resources for rebuilding homes and livelihoods; deciding when, how and where to rebuild; acquiring skills or technical guidance; rebuilding in altered or disrupted physical environments; negotiating national and local bureaucracies, rules and regulations; ensuring family security and safety; and coping with the psychological consequences of disaster. The degree of choice open to households is influenced not only by the extent of their disaster losses, but also by: poverty level; social status; connections (social and political); housing, land and property rights and tenure systems; the availability and usefulness of scientific and technical knowledge and skills; and access to markets and financial and material assistance. Self-recovery was revealed as a multi-faceted, dynamic process. Households are pragmatic and adaptive: their needs, priorities and opportunities shift frequently over time and according to changing circumstances (e.g. the arrival of monsoon rains or availability of different forms of assistance) and as a consequence of the policies and interventions of different external actors.[54] Moreover, shelter programming needs to be very context-specific, since building typologies and social structures can vary widely within a country.[55]

[53] 'Promoting safer building and self-recovery in the Philippines' (2017); 'Promoting safer building and self-recovery in Nepal' (2017); 'Promoting safer building and supporting self-recovery: report of Promoting Safer Building Multidisciplinary Conference, Royal Geographical Society, London, 13 July 2017'.

[54] Twigg *et al.* (2017); Schofield *et al.* (2019); Sargeant *et al.* (2020).

[55] Flinn and Echegaray (2016).

Building back safer

The safety argument has been central to self-recovery discourse. Humanitarian agencies' support to self-recovery has focused on ensuring that householders do not simply repeat unsafe designs and building practices. It is axiomatic within the humanitarian shelter sector that making houses safer should be a primary goal of reconstruction programming: one of the 10 'Key Propositions for Building Back Better' in the Clinton report on the 2004 tsunami is that 'Good recovery must leave communities safer by reducing risks and building resilience'.[56] However, the widely used terms 'safe' and 'safer' are relative and imprecise. They need to be defined—and where possible, measured—in relation to different construction techniques and technologies. Humanitarian responders and householders may have different safety priorities: the former focusing on safety from environmental hazards; the latter more aware of other forms of safety, such as privacy and security from crime and violence.[57]

Rebuilding depends on the availability of finance, technical skills and support, and appropriate construction materials. Reconstruction programmes facing time and resource limitations invariably have to weigh up housing quality against speed of delivery and quantity. Households and agencies face difficult operational decisions about what level of safety is desirable and achievable, and what is good enough or fit for purpose. Several factors make it difficult for householders to adopt safer construction: these include lack of understanding of safer building methods, the higher cost of hazard-resistant construction techniques, the amount of technical and financial support available, and the demands of local building codes.[58]

The choice-based approach that self-recovery implies also creates ethical questions that are often overlooked in the literature on shelter and disasters. It transfers some ownership of risk from relief agencies to households. Whilst NGOs and other technical support organisations can give good advice and encourage safe practice in construction and site choices, self-recovery means that decision-making rests with the families concerned. Humanitarian agencies have to make trade-offs between achieving high levels of safety in a smaller number of houses or reaching a much larger number of houses with a lesser degree of safety. Building back safer may not be the top priority for families—restoring livelihoods is often the most immediate need—and assisting agencies may have to focus on ensuring that households make well-informed decisions.[59]

56 Clinton (2006: 22–3).

57 Flinn (2020).

58 Harriss *et al.* (2020).

59 Flinn (2019); Twigg *et al.* (2017); Parrack *et al.* (2014).

Expanding the scope of self-recovery

The two field research projects and the events, publications and outputs that they generated have widened the scope of enquiry beyond the effectiveness of humanitarian assistance. Self-recovery appears to have been a catalyst for a more holistic perspective on recovery and reconstruction, taken up by research team members or independently by other researchers. Additional UK research council funding to translate research into practice has supported a new collaborative project to develop best-practice guidance for supporting self-recovery processes, drawing on the the research projects and operational experiences.[60] This has led, for example, to work on how dynamic, multi-hazard environments affect household and community self-recovery. Here, researchers have used land systems mapping to understand the physical aspects of the landscape and implications for safer rebuilding. Following on from this, a workshop was held for representatives from the international geoscience and humanitarian communities to share experiences of cross-disciplinary working, explore how geoscience could be a resource in humanitarian shelter practice, and start a conversation on collaboration.[61]

Knowledge exchange regarding rebuilding houses, and drivers and barriers relating to adoption of hazard-resistant construction knowledge by disaster-affected households, have also been investigated.[62] A review commissioned by InterAction (a USA-based coalition of international NGOs) has considered the impacts of shelter and settlements assistance on health (physical and mental), livelihoods, hazard risk, social cohesion and gender.[63]

Shelter and health has emerged as an important area of investigation, looking beyond environmental hazards to a wider range of risk factors (including indoor air pollution, overcrowding, thermal extremes, poor sanitation and unsafe water) and considering how humanitarian shelter interventions might address these.[64]

Conclusion

The rapid adoption of self-recovery ideas and practices is remarkable. This could be seen as the latest stage in the decades-long evolution of humanitarian agencies' approaches to shelter reconstruction, building on previous participatory and

[60] Self-recovery housing for development: scaling up crisis preparedness and humanitarian shelter response. Engineering and Physical Sciences Research Council EP/T015160/1.

[61] Simons and Sargeant (2020).

[62] Hendriks (2017); Hendriks and Stokmans (2020).

[63] Kelling (2020).

[64] A recent one-day webinar on this subject attracted more than 100 academics and practitioners from around the world: Webb *et al.* (2020).

owner-driven approaches. However, many experienced shelter professionals regard it as more innovative. It exemplifies adaptive capacity and practice, but can even be seen as transformative, since transformation implies elasticity, diversity, innovation (of processes, methods, institutional relationships, technologies) and empowerment.[65] The relative open-endedness of the self-recovery idea makes it inclusive and allows for variations in approach.

The enabling environment has been favourable for introducing self-recovery—indeed, self-recovery proponents seem to have been pushing at an open door. The international humanitarian shelter sector encourages innovation. Its culture is reflective and often highly self-critical, with a strong desire to learn and improve. Its performance, both sector-wide and in individual disasters, is regularly reviewed. Since 2007, the Global Shelter Cluster has published seven *Shelter Projects* volumes: compendiums of experiences of shelter response and reconstruction in recent disasters worldwide, looking at strengths, weaknesses and lessons learned. The 2018 *State of Humanitarian Shelter and Settlements* report, also published by the Global Shelter Cluster, was a wide-ranging review of the sector's work and impact, identifying achievements and challenges.[66] Regular meetings of shelter practitioners and academics—in particular, the Shelter and Settlements Working Group in the USA, hosted by InterAction, and the UK Shelter Forum[67]—are open events to discuss new ideas and approaches, and strengthen consensus. This is a strong, dynamic community of practice. The sector seeks to widen its scope and embrace new thinking and practice in order to achieve greater impact. For example, recent years have seen growing interest in area-based and settlements approaches, which place shelter reconstruction in its wider spatial and locational context.[68]

Self-recovery is not a universal solution to the humanitarian shelter problem and there are some significant gaps in the way it is perceived and applied. For instance, it has yet to link to the wide, long-running academic discourse on informality and emergence in disaster contexts. Spontaneous responses by self-organising, emergent voluntary groups and individuals, drawing on existing social capital and networks, are a common feature of disasters, and an important resource and capacity for emergency response, although they are usually overlooked by formal aid organisations.[69] This still receives very little attention from the shelter sector.

Another major gap is that self-recovery conversations, thinking and implementation are led largely by international aid agencies. Other actors, particularly national

65 Twigg *et al.* 2020.

66 http://shelterprojects.org/.

67 www.interaction.org/working-groups/; www.shelterforum.info/category/united-kingdom/

68 Parker and Maynard (2015); Setchell (2018).

69 Stallings and Quarantelli (1985); Drabek and McEntire (2003); Whittaker *et al.* (2015); Twigg and Mosel (2017).

and local governments, are far less visible in public discourse on the subject, and sometimes appear to be seen more as targets for influencing than as partners.

Finally, it should be noted that post-disaster recovery is a complex, non-linear, dynamic process which often takes place in rapidly changing conditions. Endpoints cannot easily be defined, making it difficult to measure success.[70] The very term 'recovery' is open to a variety of interpretations, depending on different knowledges, experiences and perspectives. It implies a process of improvement and return to some kind of normality that many disaster-affected people may not be able to obtain. This overlooks the fact that post-disaster contexts are likely to be very different from pre-disaster conditions, creating a 'new normal' with different demands and priorities.[71] It may be more realistic and constructive to think in terms of post-disaster 'transitions', encompassing a range of options and strategies for managing greatly altered environments over extended periods of time. Self-recovery practices will grow and adapt to such contexts. Further, longitudinal, studies could inform our understanding of such processes and the role that self-recovery plays.

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[70] Johnson and Hayashi (2012); Blackman *et al.* (2017).

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Insights from vulnerability-driven optimisation for humanitarian logistics

Douglas Alem

Abstract: Natural disasters and the vulnerability of a population go hand in hand. We cannot understand the level of a disaster without grasping the extent of people's vulnerability. But how can we ensure that humanitarian assistance is driven by people's vulnerability when the lack of resources makes it impossible to support all those that need it? This study thus contributes to this line of research by enhancing our understanding of how we can 'put the reality of the most vulnerable people first' (cf. Chambers 1995). For this purpose, we examine two experiences that have proposed to incorporate vulnerability concerns into the planning and optimisation of humanitarian logistics operations. The first experience relies on a very popular composite indicator called Social Vulnerability Index (SoVI) to build enhanced response capacity in more vulnerable areas. The second experience is built upon a poverty measure called Foster-Greer-Thorbecke (FGT) to identify the groups that potentially need the most relief aid supply and to help devising allocation plans in compliance with people's income. These two experiences reveal that in most cases targeting more vulnerable areas increases their level of access to relief aid goods without greatly compromising the relief service levels of less vulnerable areas.

Keywords: Social Vulnerability Index, FGT poverty measure, disaster management, humanitarian logistics, disaster relief optimisation.

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1 Introduction: disasters as social phenomena

In order to mitigate people's suffering in the aftermath of a disaster, humanitarian logisticians have to deal with complex decision-making processes that are nearly always complicated by socioeconomic conditions, severe uncertainty and lack of available resources, among others. These complicating factors can be even more pronounced in developing economies where higher levels of income concentration and social inequality create groups of people who are excluded in economic, social and political terms. When a natural hazard, such as floods or landslides, strike these groups of people, it is likely that they will experience more hardship in coping with its post-effects due to their *vulnerable* situation. This in turn may reduce their potential for recovery due to lack of insurance, savings/loans, relief aid, inefficient government and slow decision-making (Chang & Falit-Baiamonte 2002), thus intensifying previous economic stress and problems (Fothergill & Peek 2004).

The idea that disasters impacts and effects are the product of the socioeconomic and political processes that different groups of people are submitted to have been pointed out by academics and practitioners over the past decades. For example, Sapir & Lechat (1986) showed that disaster-induced mortality and morbidity are a function of physical and socioeconomic conditions of the affected people. Moreover, they suggested that poorer countries usually exhibit worse disaster-generated mortality rates than richer ones due to the inability of the former in reducing their overall vulnerability. For Cannon (1994), it is fundamental the understanding that hazards are natural, but disasters are not, as they depend on the people's vulnerability. For this reason, they claimed that differences in socioeconomic factors might result in hazards having an unequal degree of impact at distinct locations. For example, the 2010 Haiti earthquake of scale 7.0 caused 2 million victims, whereas the 2011 Japan earthquake of scale 9.0 resulted in 402,069 victims (da Costa *et al.* 2014). Such difference is usually explained by the economic development gap between these countries that lead to different coping capacities.

Although the precise meaning of vulnerability varies according disciplines, it is usually accepted that it represents 'the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards' (UNISDR 2008: 22). The vulnerability to natural hazards also evidences the capacity of a given community to 'anticipate, cope with, resist and recover from the impact of a natural hazard' (Wisner *et al.* 2003: 11), which is also aligned with the concept of vulnerability to climate hazards adopted by Gough *et al.* (2019) that is based on 'the level and duration of exposure of a receptor, the sensitivity of a receptor to harm, and the capacity of a receptor to adapt'. In this sense, there has been a great effort amongst scholars to quantify or measure vulnerability via indicators or scores, such that stakeholders and policymakers can use those indicators in a *predictive* fashion to help in the identification, proposal and evaluation of effective policies and actions, as well as the most useful coping responses (Smith 2013). However, the utilisation of vulnerability indicators in a *prescriptive* way to drive humanitarian logistics operations (HLO) towards benefiting vulnerable people and/or communities is rarely found in the literature.

Our aim is then to examine and analyse two experiences with a new emerging field of research, which we are calling *vulnerability-driven optimisation* for humanitarian logistics. In simple words, vulnerability-driven optimisation consists of: (1) an optimisation component designed to improve HLO decisions; and (2) a vulnerability-based criterion to drive such decisions in such a way as to prioritise the allocation of (scarce) resources and services to vulnerable people. The two experiences report the utilisation of vulnerability-driven optimisation in the Brazilian humanitarian supply chain. The motivation in pursuing this study for the Brazilian case is twofold: (1) Brazil is among the ten countries most affected by weather-related disasters in the last 20 years (Wahlstrom & Guha-Sapir 2015); (2) many recent disasters in Brazil are consequence of social processes whose primary characteristic is the unequal distribution of opportunities and social inequality that push more vulnerable people to risky areas (Carmo & Anazawa 2014). The two experiences are based on recent academic studies (Alem et al. 2021a; 2021b), and differ in the way the optimisation component is designed, as well as in the *proxy* for vulnerability that is adopted to prioritise the humanitarian assistance to disaster victims.

Following this introduction, the next section presents a brief background of optimisation and decision-making in humanitarian logistics, vulnerability approaches and measurements, as well as some context on the Brazilian humanitarian supply chain. The subsequent sections describe the two experiences with vulnerability-driven optimisation for humanitarian logistics. The first experience relies on a very popular composite indicator called Social Vulnerability Index (SoVI) to build enhanced response capacity in more vulnerable areas. The second experience is built upon a poverty measure called Foster-Greer-Thorbecke (FGT) to identify the groups that potentially need the most relief aid supply. The two experiences main goal is to help devise allocation plans in compliance with people's vulnerability. Insights into the two experiences are then reported. Finally, policy implications and limitations of the framework are discussed in the concluding remarks.

2 A potpourri of optimisation, vulnerability and the Brazilian humanitarian supply chain

The first part of this section briefly provides some background on optimisation and decision-making in humanitarian logistics, whereas the second part focuses on understanding vulnerability metrics and some approaches. Finally, the third part addresses the Brazilian humanitarian supply chain and some challenges that motivated the development of decision support models. It is important to mention that there is no intention to be exhaustive in the presentation of the definitions and concepts.

2.1 Optimisation and decision-making in humanitarian logistics

As we already mentioned, the vulnerability-driven optimisation approach consists of two components: an optimisation procedure and a vulnerability-based criterion. An optimisation procedure is simply a mathematical (thus quantitative) model that represents, through equations and inequalities, a given decision-making problem. This class of mathematical models belong to the so-called *mathematical programming* field; here, 'programming' is in the sense of 'planning', not 'computer programming'; see Williams (2013) for an introduction in this subject. The process of using mathematical programming to support decision-making usually encompasses the following phases: (1) identifying and formulating the problem; (2) building the model; (3) validating the model and performing the analyses; and (4) implementing the findings and updating the model. These phases and their corresponding overviews are illustrated in Figure 1.

In humanitarian logistics and disaster management, typical decision-making problems rely on the humanitarian logistics operations associated with the disaster life cycle, or disaster management cycle, which is a framework popularly utilised in disaster management to understand, visualise and delineate the distinct stages of a developing disaster event. 'Its main purpose is to tie the temporal dimension of an emergency with the appropriate functions for its successful management' (Young *et al.* 2020). Diverse authors summarise the disaster management cycle in two phases only (e.g. Tufekci & Wallace 1998): before disaster strikes (pre-event), whose main goal is to identify risks and take mitigating measures; and after disaster strikes (post-event), whose primarily objective is to manage the allocation of scarce resources.

The main activities commonly related to these two phases are described in Table 1. Both phases involve logistics planning and supply chain design, e.g. the construction of emergency operations centres (location), the maintenance of emergency supplies

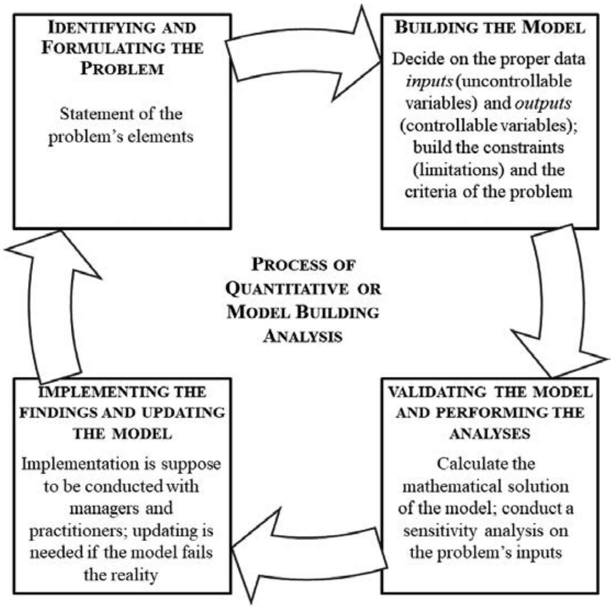

Figure 1. The process of quantitative or model building analysis (adapted from Wagner, 1975).

Table 1. Typical activities in preparedness and response of disaster operations management (adapted from Altay & Green 2006; Carter 2008).

Preparedness	*Response*
Construction of an emergency operations centre	Activating the emergency operations centre
Formulating and maintaining emergency planning	Implementing the emergency plans
Training programmes, including exercise and tests	Urban search and rescue
Maintaining emergency supplies	Providing emergency food, shelter, medical assistance, etc.
Public education and awareness	Emergency infrastructure protection and recovery of lifeline services
Budgeting for and acquiring vehicles and equipment	Managing donations
Emergency communications	Budgeting for activating response plans, e.g. transportation of commodities
Making safe boats and vehicles	

(prepositioning), the supply of emergency commodities (transportation), and so on. All these activities are included in the field of humanitarian logistics, defined as the process of planning, implementing and controlling the transport and storage of goods and materials from the point of origin to the point of consumption, in order to relieve the suffering of vulnerable people (Thomas & Kopczak 2005).

Alternatively, Figure 2 depicts an example of the disaster management cycle evidencing the four typical phases: (1) preparedness; (2) response; (3) recovery; and (4) mitigation. Each phase has distinct characteristics and activities to achieve the goals of the disaster relief operation. For example, one of the most popular strategies to supply victims' needs in the disaster aftermath is via *prepositioning* of goods in the preparedness phase (before the disaster strikes), whose underlying idea is to maintain a reasonable stockpiling of relief aid goods, such as water gallons and medicine at, or near the point of planned use in case the disaster really happens. This in turn reduces the transportation lead-times to the affected areas, thus increasing the chance of supplying the most vulnerable victims within the first few critical hours. No need to say that these activities can substantially vary depending on the disaster type and scale, geographical area and so forth. On this note, it is worth mentioning that although there is not a unique disaster classification system, most papers in the humanitarian logistics literature have been used a disaster classification based on three aspects of disaster events (Van Wassenhove 2006; Apte 2010): (1) the speed of onset, slow or sudden; (2) the location, localised or dispersed; and (3) the source of disaster, natural or man-made (also called as *technological*). L'Hermitte *et al.* (2014) proposed a logistics-focused classification for disasters based not only on time and geographic scope, but also five *situational factors* that reflect the impact of the external environment on the set of logistics operations and the corresponding performance of the humanitarian response, which were identified as: (1) the government situational factors;

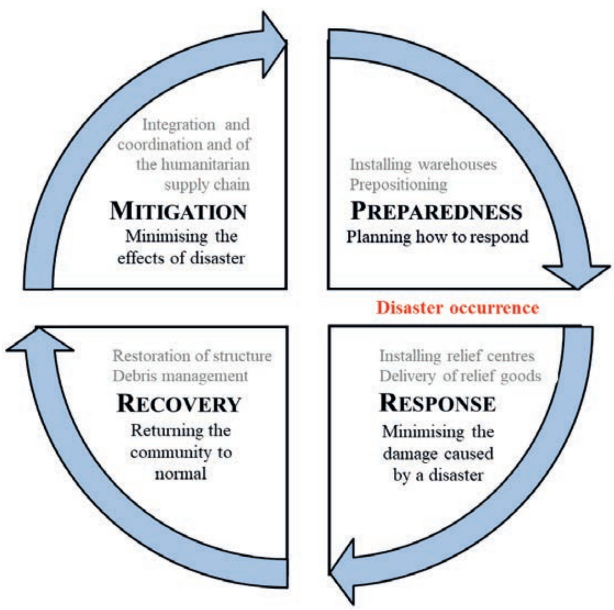

Figure 2. The disaster management cycle (adapted from Cozzolino, 2012; https://www.gdrc.org/uem/disasters/1-dm_cycle.html).

(2) the socioeconomic situational factors; (3) the infrastructure situational factors; (4) the physical situational factors; and (5) the security situational factors. A more recent classification focused on 'the impacted system and resulting interactions' correspondence to humanitarian-relief supply chain design' is developed in Mackay *et al.* (2019), where the authors acknowledged six disasters' factors that should be taken into account when proposing a disaster typology model: (1) speed of onset; (2) time horizon; (3) spatial considerations; (4) affected population needs; (5) perceived probability of occurrence; and (6) perceived magnitude of consequence. The International Disaster Database (EM-DAT)[1] also classifies natural disasters in five sub-groups: (1) geophysical (e.g. earthquake, volcano, mass movement—dry); (2) meteorological (e.g. storm); (3) hydrological (e.g. flood, mass movement—wet); (4) climatological (e.g. extreme temperature, drought, wildfire); and (5) biological (e.g. epidemic, insect infestation, animal stampede), covering 12 disaster types and more than 30 sub-types.

Although the practitioner's expertise is a key factor to conduct effective humanitarian logistics operations, Gonçalves (2011) showed that humanitarian decision-makers very often make use of non-optimal decisions in practice by over-reliance on past experience, over-confidence in their own unaided decision-making abilities, and the use of simple decision heuristics. These issues have motivated scholars to adopt mathematical programming tools to optimise humanitarian logistics activities over the past years, especially because 'emergency logistics in disasters is fraught with planning and operational challenges, such as uncertainty about the exact nature and magnitude of the disaster, a lack of reliable information about the location and needs of victims, possible random supplies and donations, precarious transport links, scarcity of resources, and so on' (Alem *et al.* 2016: 187). Mathematical programming models can help not only to circumvent the severe limitations of decision-making unsupported by prescriptive models, but also to capture, integrate and coordinate important decisions that must be made by policymakers effectively, efficiently, and equitably.

2.2 Vulnerability and its measurement in humanitarian logistics

The concept of vulnerability emerged from social sciences research, but its meaning substantially varies across disciplines (Janssen & Ostrom 2006; Fordham *et al.* 2013). There are several papers focused on exploiting and mapping vulnerability for both policy analysis and intervention purposes. For Adger (2006: 268), 'the concept of vulnerability has been a powerful analytical tool for describing states of susceptibility to harm, powerlessness, and marginality of both physical and social systems, and for guiding normative analysis of actions to enhance well-being through reduction of risk'. For Cutter *et al.* (2003: 6), 'vulnerability science helps us understand those

[1] See more in www.emdat.be/

circumstances that put people and places at risk and those conditions that reduce the ability of people and places to respond to environmental threats'. Various scholars understand that vulnerability to natural hazards is a combination of physical conditions and socioeconomic factors primarily derived from (income) class, gender and ethnicity (Cannon 1994; Bankoff 2003; Birkmann 2007).

Despite the fact that vulnerability can be seen through different lenses, it seems there is a general consensus within the social science community on the main drivers of vulnerability, or in other words, the factors that raise vulnerability levels. These include age, gender, disability, poverty, race, life expectancy, occupation, political system, education and food aid (Smith 2013). Cannon (1994) summarised the vulnerability types as degree of resilience (livelihood resilience), self-protection and social protection, as presented in Figure 3. Whereas the livelihood resilience is strongly determined by the aforementioned factors such as income (class), gender and ethnicity, self-protection is mainly seen as hazard-specific, thus return, period, intensity and magnitude are the main determinants. Finally, social protection is generally attributed to the level of scientific knowledge that enables state and other social/political bodies to protect people from a natural hazard.

It is not easy to objectively measure vulnerability in such a way that the assessment can be used for practical policy interventions (Smith, 2013). Mostly probably for this reason, scholars and practitioners continue to come up with novel vulnerability metrics and indices whose goals include the identification, assessment, visualisation and communication of diverse levels of vulnerability faced by local and global communities. Examples of vulnerability indexes include the so-called Social Vulnerability Index (SoVI), which is considered one of the most popular composite[2] indexes of overall social vulnerability, and it is employed in this article to prioritise more vulnerable people in disaster relief efforts. Despite of this effort in the development of new

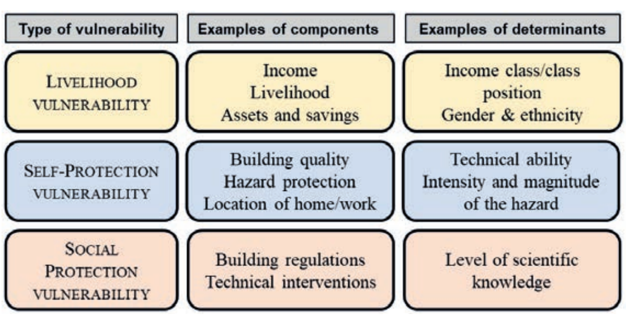

Figure 3. Vulnerability types, components and determinants (extracted and adapted from Cannon, 1994).

[2] Indicators are statistics that provide some sorts of measurement to a particular phenomenon of concern (Wong 2003). Composite indexes, such as SoVI, are statistics composed of more than one indicator.

vulnerability metrics and indicators, their utilisation within optimisation and decision-making in humanitarian logistics is still in its infancy. Most papers that somehow attempted to incorporate vulnerability issues within decision support tools used socioeconomic indicators instead of explicitly defining their vulnerability concept or criteria.

This is the case of, for example, Horner and Downs (2008) that approached the interrelationships between socioeconomic status and relief distribution via the evaluation of people's needs based on the percentage of people living below the poverty line at Leon County in Florida, USA. El-Anwar *et al.* (2009) focused on the assignment of displaced families after a disaster to a number of alternative housing projects. For this purpose, they proposed to use socioeconomic indicators to build four indexes designed to address sustainable development, namely, environmental performance, social welfare, economic, and public safety. In particular, the welfare index took into account different indicators at the housing location, such as employment and educational opportunities, housing quality/delivery time, healthcare and overall essential services opportunities/access. El-Anwar *et al.* (2010) and El-Anwar (2013) also focused on housing arrangements problems using similar indicators. The work of Noyan *et al.* (2016) might be seen as an extension of Horner and Downs (2008) in which the authors characterised the concept of accessibility for a last-mile distribution network problem based on physical and socioeconomic factors, such as the proportion of vulnerable population, which was assumed to be composed by people with low mobility at the demand nodes, such as disabled people, people aged over 65 and females with children. Sutley *et al.* (2017) merged what they called an *engineering model* with specific socioeconomic metrics attempting to produce an improved framework to assess the allocation of mitigation funds for woodframe building stock. Their proposed decision support model balances the initial retrofit cost, the economic loss, the number of morbidities and the time to recovery. In particular, the number of morbidities were determined according to a set of socioeconomic data, such as income, household size, age, ethnicity/race, family structure, gender and socioeconomic status. Other papers, such as Chong *et al.* (2019) and Maharjan *et al.* (2020) and some references therein, focused on the physical vulnerability of their study areas to build decision support models aligned with the population needs/profile. In the first case, the main goal was to design a model to find the areas and facilities necessary for humanitarian logistics in sudden disaster response situations, whereas the second case analysed how to determine the best placement of mobile logistics hubs for emergency preparedness and response in Nepal. More recently, Kougkoulos *et al.* (2021) devised a multi-method approach combining satellite-based remote sensing tools for identifying informal migrant worker settlements, ground truthing inspections, and a Multi-Criteria Decision Analysis (MCDA) model. The main goal was to develop a decision support tool to be used by governments and humanitarian organisations that can assess labour exploitation risks in different settlements and to prioritise their interventions. For this reason, the authors collected several indicators that were used to understand the level of vulnerability of the informal settlements, such as hygiene conditions and safety measures, and thus to provide their ranking from highest to lowest risk of labour exploitation.

In the comparative analysis of disaster risk, vulnerability and resilience composite indexes, Beccari (2016) revealed that there may be important differences in the methodology used to construct them, such as type and number of variables. However, the agreement amongst scholars is that low income status (or poverty) increases social vulnerability. Hallegatte *et al.* (2016) indeed found that poverty is a major driver of people's vulnerability to natural hazards. The authors explain that poor people frequently have to settle in risky areas and benefit less from protection against natural hazards. Also, it was found that poor people are more often exposed to floods, droughts and extreme heat (Hallegatte & Rozenberg 2017). Moreover, those populations that were less successful in the recovery process are likely to be more vulnerable to the next hazard strike (Cannon, 1994). For the World Bank:

> *Disasters impact the poor much more than the rest of the population. The poor have much lower resilience capacities than other sectors of the population. We have seen recent studies by the World Bank indicating that disasters are pushing some 26 million people into poverty each year. This is because some live in high-risk areas and have little capacity to recover from disasters. It is something we are working on, but where much remains to be done. (World Bank 2017)*

Focused on the Brazilian reality, Valencio (2009) also affirms that poverty is indeed the most relevant variable to explain vulnerability in the context of rainfall in Brazilian cities.

Adger (2006) claims that several of the challenges involved in quantifying vulnerability have been tackled by assessing vulnerability using poverty measures. The author also proposes what is called a *generalised measure of vulnerability*, which is based on the popular class of poverty measures called Foster-Greer-Thorbecke (FGT) from Foster *et al.* (1984). Poverty measures are very popular in social sciences and economics, and aims at describing how poverty is distributed in a given population or groups of people. This assessment can help policymakers to devise proper anti-poverty policies and allocate scarce resources, amongst others. The literature concerning the proposition of poverty measures is rich and has shown a considerable number of different measures over the past years. However, as far as we know, there have not been academic efforts to use the FGT poverty measure within decision support models in humanitarian logistics to prioritise the poor. In this article, we show an example of how the FGT poverty measure can be useful for this purpose.

2.3 Because context matters: the Brazilian humanitarian supply chain and challenges

Brazil's National System for Protection and Civil Defence (SINPDEC) is responsible for the country's disaster management. SINPDEC comprises of diverse entities that together carry out the disaster operations management for the entire country. The National Department for Civil Protection and Defence (SEDEC) is the main body of SINPDEC. SEDEC is divided into four main departments that coordinate the planning, articulation and execution of civil defence and protection programmes, projects and actions. The National Centre for Risk and Disaster Management (CENAD) activities comprise of managing the strategic actions of preparedness and response in the Brazilian territory. The Department of Liaison and Management (DAG) supports, supervises and promotes programmes and plans guidelines related to the National Policy of Protection and Civil defence (PNPDEC), and for this reason, its action spans the entire disaster lifecycle. The Department of Disaster Mitigation (DMD) develops and implements preparedness programmes, including typical activities of mitigation, prevention and preparedness. The Department of Rehabilitation and Reconstruction (DRR) supports programmes in the response phases associated to rehabilitation and reconstruction (Alem *et al.* 2021a). The practices of all these entities are more complex and entail more responsibilities, but this discussion is beyond the focus of this article.

Currently, the Brazilian civil defence adopts a strategy for relief aid procurement, the so-called 'Price Registration System' (SRP in Portuguese abbreviation), attempting to complement the humanitarian assistance provided by states and municipalities faced with disasters. Basically, the suppliers that are able to provide and distribute a required product to a given geographic area are selected via a bidding process ('lower price strategy' or 'competition', Law no. 8.666) and registered in a 'Price Registration Form' (ARP in Portuguese abbreviation) that must contain information on their supply capacity, price and transportation lead-time. To request relief aid in either pre- or post-disaster phases, the applicant (state or municipality) must solicit it from SEDEC and SEDEC thus analyses the necessity of the applicant and authorises (or not) the requisition. If the solicitation is approved, the suppliers are ordered by SEDEC to transport the approved quantity of relief aid to the capital of the state where the applicant belongs.

The relief distribution from the capital to the municipalities is then performed with support of the state and municipal coordination bodies called CEDEC and COMDEC in the case of a disaster. The selected suppliers must transport the required quantity of relief aid to the capital of the corresponding municipality (applicant) within 192 hours for the North Region and 96 hours for the remaining Brazilian Regions. According to SEDEC, the federal government plays a secondary role in the relief distribution because it is presumed that the primary humanitarian assistance will be an initiative of the affected state or municipality (immediate response). However, if the affected municipality/state struggles to raise in-kind donations and funds to supply victims' needs immediately after disaster strikes, it is unlikely that relief assistance will arrive within the 48 critical hours, which might undermine the effectiveness of the overall humanitarian operation. To overcome this potential drawback, it is possible to adopt a prepositioning strategy attempting to maintain a reasonable stockpiling of relief goods at, or near the point of planned use. If on one hand prepositioning has the disadvantage of being sometimes prohibitively complicated and expensive (Balcik & Beamon 2008), on the other hand, this practice is also one of the most effective strategies to deal with several types of disasters (Apte & Yoho 2011; Alem *et al.* 2021a), such as sudden- and slow-onset ones.

In this context, the idea of both the decision support models to be described in the following sections is to help SINPDEC as well as other state/municipal bodies in charge of disaster management to plan, integrate and coordinate key HLOs that must be performed to meet victims' needs when resources are scarce. Our main assumption is that, regardless of which body will provide the first humanitarian assistance, taking forward the idea of enhancing/optimising the current status of their humanitarian logistics will allow policymakers to understand how to effectively allocate scarce humanitarian assistance to the people most in need, which are the most vulnerable. More specifically, under an effective prepositioning strategy, primary assistance such as relief aid goods can almost immediately be distributed to the most vulnerable communities, while secondary assistance towards less vulnerable communities is deployed, e.g. via in-kind donations, local procurement, amongst other strategies. It is worth noting that our vulnerability-driven approach resembles a type of 'rationing' in the sense that both are oriented to allocate scarce resources according to some objective rule. In particular, rationing of goods/services in health care have been debated throughout the history of medical ethics because it may be controversial from the equitable distribution point of view selecting one group over another to receive treatment (Annas 1985; Tragakes & Vienonen 1998).

To take into account some challenges faced by the Brazilian humanitarian supply chain, our decision support models are optimisation-based (see Section 2.1), and entail an objective function to be optimised (our criterion) and a group of constraints that reflect the problems' requirements. One of the main challenges, as already mentioned, is the scarcity of overall resources (money, relief aid goods, etc.) to perform humanitarian logistics operations. That is why our decision support models are both based on finding the most effective decision (allocation of humanitarian assistance/resources such as relief aid good), which can be understood as maximising the number of victims that will receive the appropriate humanitarian assistance considering their specific needs and vulnerability profiles. As a consequence of having scarce resources, planning how to satisfy victims' needs is a key concern to guarantee that humanitarian assistance will be impartially allocated and will be aligned with victims' needs and profiles. Other challenges refer to how many facilities (warehouses, relief centres, etc.) to establish, where to locate them, and at which capacity. Indeed, there might be a trade-off between the transportation costs advantage of decentralising (more but smaller) facilities near major disaster-prone areas and the operating costs advantage of consolidating (fewer but larger) facilities not necessarily near major disaster-prone areas. Particularly in continental-size countries like Brazil, finding the best trade-off is crucial to guarantee effective and efficient humanitarian logistics operations; clearly, this also encompasses the evaluation of the best transportation modes, such as trucks, small aircrafts and helicopters. All these challenges will be represented by a group of six main optimisation constraints in our decision support models. The main rationale of these constraints is discussed below.

Location constraints. The location constraints ensure that facilities such as warehouses, depots and relief centres can only be established in pre-approved sites that already have a basic infrastructure. These constraints can avoid that a facility is established 'too close' to another, and they also limit the maximum number of facilities that can be established. Finally, the location constraints can also be used to restrict the capacity of such facilities, e.g. warehouses cannot store any quantity of relief aid goods, as well as relief centres cannot accommodate any number of victims.

Prepositioning constraints. The prepositioning constraints guarantee that there will be a minimum quantity of prepositioned relief aid goods in warehouses/relief centres to be economically viable to install them. These constraints are necessary because it does not make sense to install a warehouse to store one gallon of water, for example. The prepositioning constraints also state that there is a maximum quantity of each type of relief aid good to be prepositioned over all the disaster-prone areas. This quantity is usually *a priori* agreed by private suppliers and public bodies or non-governmental organisations in charge of disaster relief operations.

Logical constraints. The so-called logical constraints help to link several constraints in attempt to avoid nonsensical decisions. For example, if a given warehouse, say '*n*', is *not* established at a disaster-prone area, say '*a*', then there is no way to prepositioning relief aid goods at disaster-prone area *a*. Analogously, if a given relief centre is not open, we cannot send victims to it.

Conservation flow (or victims' needs balance) *constraints*. The conservation flow constraints guarantee that victims' needs will be fulfilled; in case of insufficient resources to meet all victims' needs at once, these constraints also take into account the unfulfilled needs. The conservation flow constraints also help decide which facility (warehouse and/or relief centre) will be responsible for sending relief aid goods to which disaster-prone area.

Transportation/distribution constraints. The transportation/distribution constraints are fundamental to determine which transportation modes should be adopted to send relief aid goods from warehouses to relief centres (and/or to relief centres to disaster-prone areas), and to estimate how many of each type must be used (hired or subcontracted). These constraints are also necessary to visualise which routes can/cannot be used to perform relief transportation, as some routes may be total or partially blocked[3] in the immediate disaster aftermath.

Budget constraints. The budget constraints define the pre-disaster and/or the post-disaster financial budgets for performing the humanitarian logistics operations. This way, they ensure that the total expenditure related to establishing facilities, prepositioning relief aid goods, relief transportation, as well as other activities' costs will fall within the values usually stipulated by government bodies or NGOs.

In Sections 3 and 4 we will refer to these groups of constraints when we describe the decision support models.

3 Experience 1: vulnerability-driven optimisation using the Social Vulnerability Index

The first experience is based on Alem *et al.* (2021a) and focuses on a disaster preparedness and capacity-building response problem in which SoVI is adopted as the vulnerability-based criterion whose conceptual framework is illustrated in Figure 4. The conceptual framework reads as follows: *There are key HLO decisions to be made, which are based on a number of input data, and whose main goal is to maximise the effectiveness of the response given SoVI as the vulnerability-based criterion*. The optimisation component is the mathematical programming model defined by the decisions, constraints and data, whereas the vulnerability-based criterion is solely defined by the way vulnerability is measured.

Roughly speaking, we are interested in devising a type of decision support model—as described in Figure 1—to help decide on a number of logistics operations that must be performed by the Brazilian National System for Protection and Civil Defence (SINPDEC), which is in charge of the country's disaster management. The key humanitarian logistics operations are categorised in either strategic (long-term) or tactical (mid- and short-term) decisions, which are mathematically represented via controllable outputs or variables. The long-term decisions span periods of years and mostly involve deciding on: (1) where (which Brazilian state) to establish warehouses and at what size/

[3] Indeed, a very popular problem in disaster response is the so-called *road restoration* problem whose main goal is to optimally plan how to restore damaged roads to evacuate victims and distribute relief aid goods to relief centres or disaster-prone areas; see Moreno *et al.* (2020) for more details about this problem, including computational approaches.

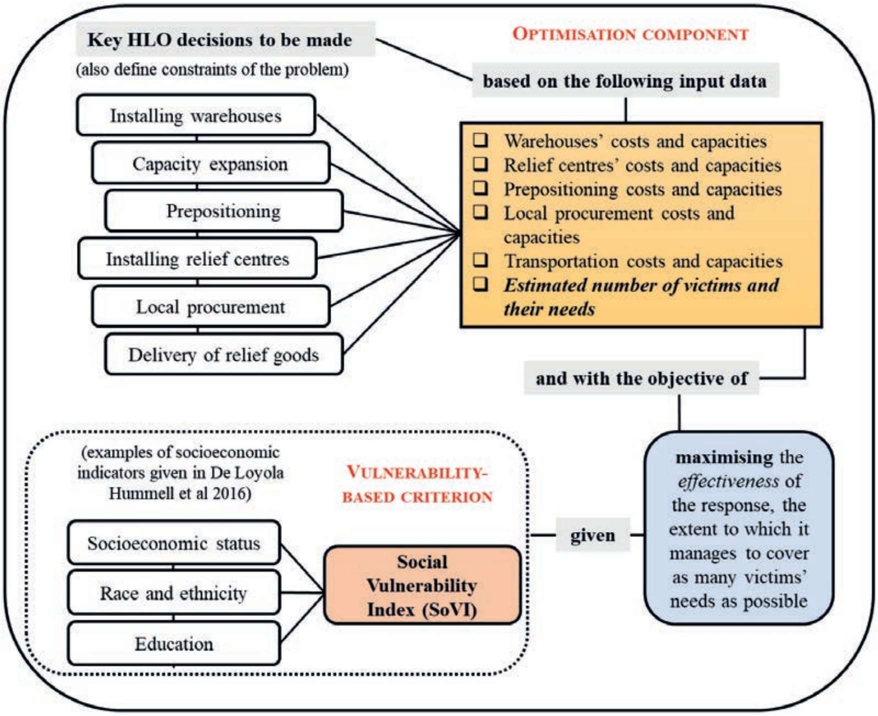

Figure 4. Conceptual framework underlying the first experience addressing the vulnerability-driven optimisation for disaster preparedness and capacity-building response in which the Social Vulnerability Index (SoVI) is adopted as the vulnerability-based criterion.

capacity they should be established; and (2) what relief aid goods should be acquired to be further propositioned at the established warehouses. Mid- and short-term decisions span shorter periods of time, such as months or even weeks, and primarily focus on: (1) setting up relief centres at disaster-prone areas; (2) performing local procurement; and (3) delivering relief aid good to disaster victims. The limitations (or constraints) of the decision support model take into account matters of network configuration for both warehouses and relief centres, expenditures, etc. The optimisation component, as shown in Figure 4, intends to find the best possible response policy (effectiveness of the response), understood here as the maximum fraction of people that will receive relief aid goods in the disaster aftermath, which is weighted by its corresponding vulnerability.

The objective of the optimisation component[4] is mathematically written as follows:

$$\max f(\mathbf{Z}) = \sum_{a \in A} \sum_{m \in M} \sum_{t \in T} \sum_{\tau \in \theta_t} \mathrm{V_a} \cdot \mathrm{v}_{\mathrm{a}\tau} \cdot \mathrm{Z}_{\mathrm{am}\tau}, \tag{1}$$

[4] We understand that it is beyond the scope of this article to discuss in details the optimisation component. The reader interested in familiarising with the full model is referred to Alem *et al.* (2021a).

where $f(Z)$ is the function to be optimised, V_a is the vulnerability-based criterion associated with disaster-prone area 'a', 'A' is the set of all disaster-prone areas, $v_{a\tau}$ is the percentage of the overall population living in area 'a' in time period 'τ', $Z_{am\tau}$ is our decision-to-be-made, representing the fraction of the population who lives in area 'a' that will receive relief aid goods from relief centre 'm' during time period 'τ', 'M' and 'T' represent the sets of all relief centres and time periods, respectively; finally, θ_t is the subset of time periods in time period t. The optimisation constraints, as discussed in the previous section, are related to location, prepositioning, logical constraints, conservation flow, transportation and budget. To illustrate an example of how these constraints work for this specific decision support model, Figure 5 shows the group of prepositioning constraints.

In this experience, the vulnerability-based criterion V_a in expression (1) is the popular Social Vulnerability Index, which is a composite indicator that has been extensively investigated over the past years within particular applications in disaster management since the seminal paper of Cutter *et al.* (2003). For many authors, SoVI can help to identify the most socially vulnerable communities (areas or regions), which can indicate the areas that need the most during the course of a disaster. In the work of De Loyola Hummell *et al.* (2016), the authors developed a SoVI index to natural hazards in Brazil to understand the differences in terms of human capacity to prepare for, respond to and recover from disasters. SoVI was evaluated based on several dimensions, such as socioeconomic status, gender, race and ethnicity, and education. Each dimension may be composed of a number of variables. For example, socioeconomic status includes three variables: the percentage of extremely poor people, the percentage of families living in households with more than one family, and the percentage of households with no phone. In Alem *et al.* (2021a), the authors claim that the adoption of SoVI in expression (1) helps prioritise supplying more vulnerable areas, i.e. those with higher (worse) SoVI values, to the detriment of less vulnerable

$$\sum_{c\in\mathscr{C}} P_{cnt} \geq p_{nt}^{\min} \cdot Y_{nt}^{w}, \ \forall n \in \mathscr{N} \wedge t \in \mathscr{T}.$$

$$\textstyle\sum_{c\in\mathscr{C}} f_c \cdot P_{cnt} \leq Q_{nt}^{w}, \ \forall n \in \mathscr{N} \wedge t \in \mathscr{T}.$$

$$\sum_{n\in\mathscr{N}} P_{cnt} \leq p_{ct}^{\max}, \ t \in \mathscr{T} \wedge \forall c \in \mathscr{C}.$$

Figure 5. Prepositioning constraints of the optimisation model. The first constraint ensures that there must be a minimum prepositioned quantity of relief aid goods at warehouse n if this warehouse is indeed established. The second constraint states that all the prepositioned goods must respect the capacity of the warehouse. And finally the last constraint guarantees that there is a maximum quantity of relief aid goods that can be deployed (prepositioned).

areas in the event of not having the resources (relief aid goods and/or money) to fulfil all victims' needs at once.

This experience relies on a number of different data types, including costs (warehouse costs, relief centre costs, transportation costs and procurement costs), capacities (prepositioning capacity, inventory capacity and transportation capacity), number of affected people (victims), victims' needs, and SoVI of the disaster-prone areas. All data was extracted from diverse sources and consolidated by the author. In this experience, the capital of 17 Brazilian states were considered as potential candidates to receive a warehouse where relief aid good should be prepositioned until their deployment in the disaster aftermath. Fifty-three disaster-prone areas of Brazil were considered as the potential affected areas to be hit by natural hazards such as floods and landslides. To evaluate the number of potential victims, we analysed the number of homeless and displaced people as a consequence of 11 types of disasters (including floods, heavy rainfalls, landslides and drought) from 1 January 2003 to 31 December 2016, which is available in the website of the 'Integrated System of Disasters Information' (https://s2id.mi.gov.br/). Based on the disaster classification models discussed in Section 2.1, our disaster dataset encompasses: (1) both slow- and sudden-onset disasters; (2) both localised and dispersed disasters; and (3) natural disasters of three main types, hydrological, meteorological and climatological.

Figure 6 shows the disaster-prone areas and the cumulative number of affected people in the past disasters. Notice that the North and South regions present some areas with very high number of victims in the period under analysis. As for the relief aid goods, we assumed that disaster victims need water, food, mattresses, dormitory items, hygiene items and cleaning items. The SoVI values[5] for the considered disaster-prone areas are exhibited in descending order in Figure 7, where we can see that 'Sudeste Rio-Grandense' is the most socially vulnerable disaster-prone area, whereas 'Centro Fluminense' is the least socially vulnerable disaster-prone area.

4 Experience 2: disaster preparedness and designing of prepositioning strategies using the FGT poverty measure

The second experience is based on Alem *et al.* (2021b) and focuses on disaster preparedness and designing of prepositioning strategies problem in which the FGT poverty measure was adopted as the vulnerability-based criterion whose conceptual

[5] These values are based on the original SoVI values evaluated in De Loyola Hummell *et al.* (2016). However, we further applied *log-transformation* to the original data in order to have positive values only and help decrease the variance of the data and, therefore, having more fairly comparable SoVI values.

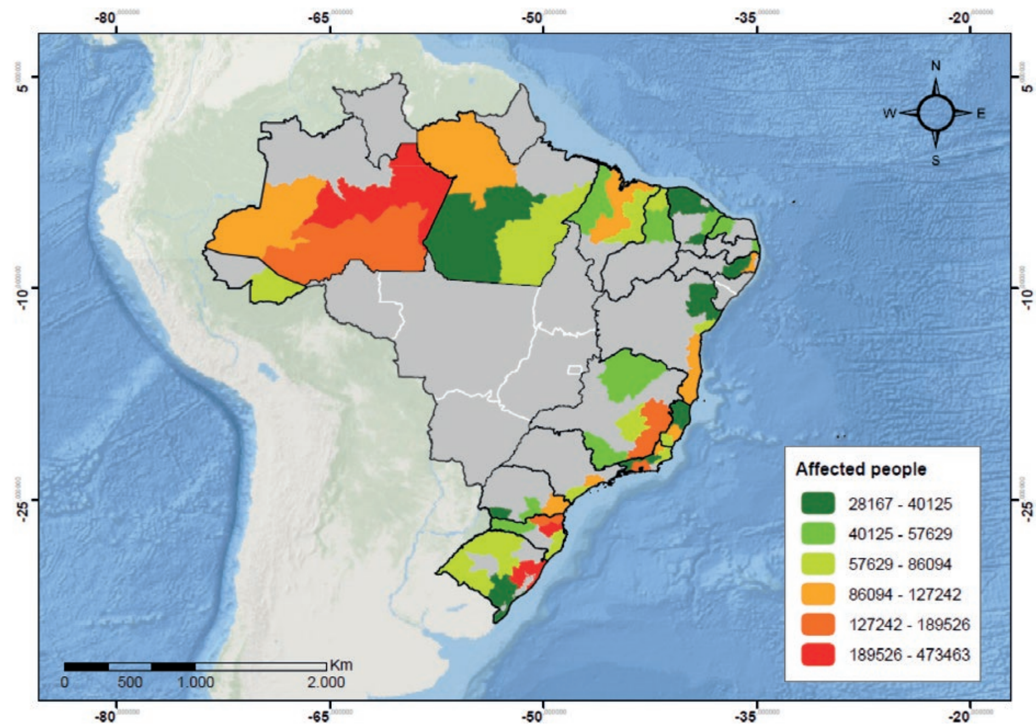

Figure 6. Number of affected people (homeless and displaced people) as a consequence of the aforementioned 11 types of disasters (including floods, heavy rainfalls, landslides, and drought) from 1 January 2003 to 31 December 2016 in all the 53 disaster-prone (affected) areas considered in the study.

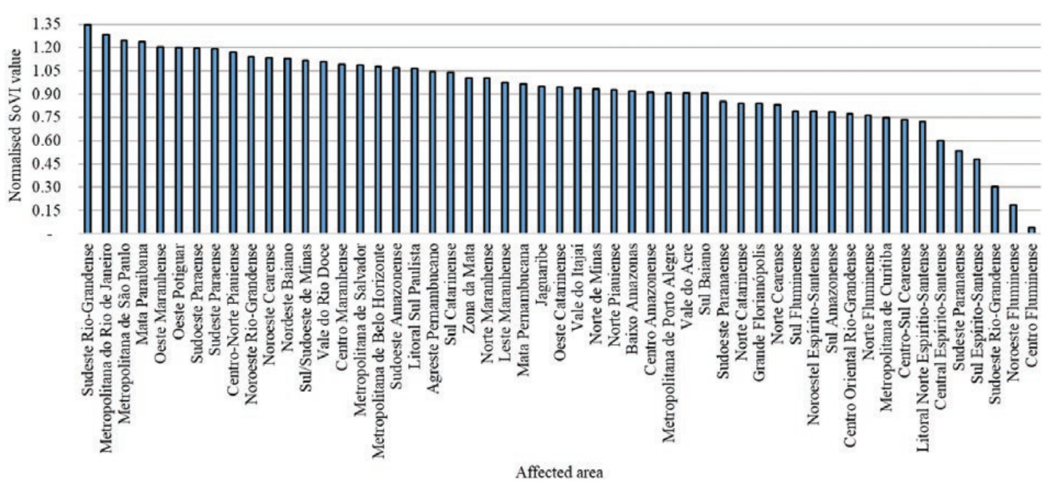

Figure 7. Normalised SoVI values for all the 53 affected areas considered in the study.

framework is illustrated in Figure 8. The conceptual framework reads as follows: *There are key HLO decisions to be made, which are based on a number of input data, and whose main goal is to maximise the effectiveness of the response given FGT poverty measure as the vulnerability-based criterion*. The optimisation component is also the mathematical programming model defined by the decisions, constraints and data, whereas the vulnerability-based criterion is solely defined by the way vulnerability is measured. Different from the first experience, now we are interested in devising a type of decision support model in which the core contribution is to evaluate whether disaster-prone areas should be prioritised or not, considering that a prioritised disaster-prone area would, ideally, satisfy the following condition. A *prioritised* disaster-prone area should satisfy three conditions: (1) it has a relief centre facility; (2) its quantity of prepositioned relief aid goods is greater than its overall needs, and it is used to cover its own needs first; (3) there is no relief aid shortage at prioritised disaster-prone areas. The aforementioned conditions intend to avoid logistics disruptions at prioritised disaster-prone areas, assuming that those areas are supposed to be more socially vulnerable and, therefore, deserve more attention. Considering that both the amount of relief aid available to be prepositioned and the financial budget to carry out the logistics

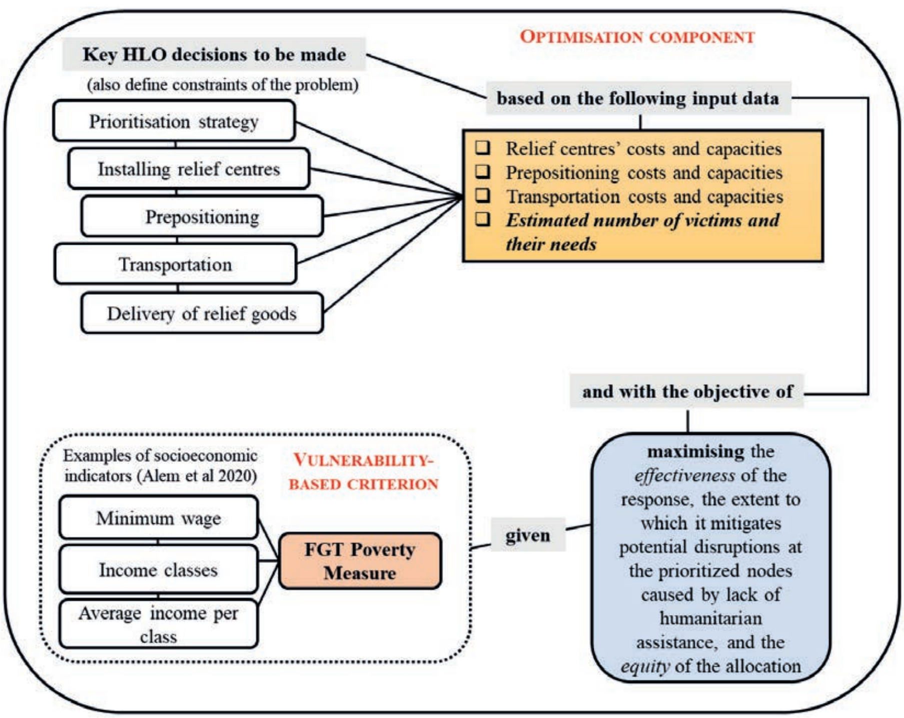

Figure 8. Conceptual framework underlying the second experience addressing the vulnerability-driven optimisation for disaster preparedness and designing of prepositioning strategies in which the FGT poverty measure was adopted as the vulnerability-based criterion.

activities are rather limited, our approach allows policymakers to select a number 'p' of potential disaster-prone areas to prioritise. The selection of which nodes should be prioritised may also be determined *a priori* by experts and given as an input of our proposed optimisation approach; in this case, the model could help assess the effectiveness of different prioritisation strategies.

The optimisation component, as shown in Figure 8, intends to find the best possible prioritisation policy (or effectiveness of the response), understood here as the extent to which it mitigates potential disruptions at the prioritised disaster-prone areas, given a set of logistics (capacity, financial, etc.) constraints. The objective of the optimisation component[6] is mathematically written as follows:

$$\max f(Z) = \alpha_1 \sum_{a \in A} V_a \cdot W_a + \alpha_2 \sum_{a \in A} P_a \cdot W_a - \alpha_3 \sum_{a \in A} U'_a \cdot W_a - \alpha_4 \sum_{a \in A} U_a / d_a, \tag{2}$$

in which $f(Z)$ is the function to be optimised, V_a is the vulnerability-based criterion associated with disaster-prone area 'a', W_a is a binary or Boolean decision variable that represents whether disaster-prone area 'a' should be prioritised ($W_a = 1$) or not ($W_a = 0$) in disaster relief efforts, P_a is also a biny decision variable that indicates whether the quantity of relief aid goods in disaster-prone area 'a' is greater than its own needs ($P_a = 1$) or not ($P_a = 0$), U'_a is another binary decision variable that shows whether there is relief aid shortage in disaster-prone area 'a' ($U'_a = 1$) or not ($U'_a = 0$), U_a is a decision variable that measures the absolute quantity of relief aid shortage in disaster-prone area 'a', d_a is the input data that represents all victims' needs in disaster-prone area 'a', and finally α_1, α_2, α_3, and α_4 are 'weights' (numerical value usually between 0 and 1) that may reflect the policymaker's perspective on the importance of each decision in expression (2). For example, if policymakers are only interested in prioritising disaster-prone areas based on their vulnerability levels, then a plausible choice for these input data would be $\alpha_1 = 1$, $\alpha_2 = 0$, $\alpha_3 = 0$, and $\alpha_4 = 0$. However, if it is important to make sure that the prioritised disaster-prone areas will receive their necessary quantity of relief aid goods, then both α_1 and α_2 must be greater than zero, and so forth. The optimisation constraints, as discussed in the Section 2.3, are related to location, prepositioning, logical constraints, conservation flow, transportation, and budget. Differently from the previous experience, we have an extra group of constraints related to prioritisation requirements. For example, we have a maximum number of disaster-prone areas that can be prioritised, and this number must aligned with the availability of resources and the capacity of public bodies in managing prioritised sites, which may require extra staff and deployment of resources. Also, if a given disaster-prone area is prioritised,

[6] We understand that it is beyond the scope of this article to discuss in detail the optimisation component. The reader interested in familiarising with the full model is referred to Alem *et al.* (2021b).

then we have to ensure that its existing relief aid goods are allocated to meet its own needs first before covering the needs of other disaster-prone areas.

The vulnerability-based criterion V_a in expression (2) is an adaptation of the Foster-Greer-Thorbecke (FGT) poverty measure developed in Foster *et al.* (1984) and aims at finding a numerical value (score) associated with the poverty of disaster-prone area 'a'. The FGT class of poverty measures is based on powers of normalised (poverty) shortfalls, it is considered simple, thus facilitating the communication with policy-makers, and satisfies desirable axiomatic properties, such as additive decomposability and sub-group consistency (Foster *et al.* 2010), which allow us to evaluate poverty across population sub-groups in a coherent way. It is worth noting that we assume that the population of disaster-prone area 'a' can be divided into extremely poor, very poor or poor, based on their average incomes. In what follows, we provide some definitions to understand how our FGT poverty measure is calculated.

Definition 1 (adapted from Alem *et al.* 2021b): The income classes represented by *extremely* poor, *very* poor and poor people have a per capita household income equal to or less than thresholds given by EP_a, VP_a, and P_a, per month, respectively. The average income of these groups are given by IEP_a, IVP_a, and IP_a, respectively.

Definition 2 (adapted from UNDP 2014): The group of people defined by the income classes designated as extremely poor, very poor and poor constitute the most socially vulnerable group.

Definition 3 (adapted from Alem *et al.* 2021b): The FGT poverty measure or poverty gap for disaster-prone area 'a' is defined as follows:

$$\mathrm{FGT}_a = \frac{H_a^{EP}}{H_a}\left(\frac{t - \mathrm{IEP}_a}{t}\right) + \frac{H_a^{VP}}{H_a}\left(\frac{t - \mathrm{IVP}_a}{t}\right) + \frac{H_a^{P}}{H_a}\left(\frac{t - \mathrm{P}_a}{t}\right), \tag{3}$$

in which

1. 't' is a poverty line or given threshold for income;
2. H_a^{EP} is the number of *extremely* poor people in disaster-prone area 'a';
3. H_a^{VP} is the number of *very* poor people in disaster-prone area 'a';
4. H_a^{P} is the number of poor people in disaster-prone area 'a';
5. H_a is the total number of people in disaster-prone area 'a'.

This experience strongly relies on historical data[7] on the number of homeless and displaced people due to natural hazards, such as floods and landslides, to estimate the potential number of victims for each Brazilian state,[8] which is available on the

[7] In the period 2007–2016.

[8] The capital of each state was considered a disaster-prone area. More information about how data was consolidated and generated can be found in Alem *et al.* (2021b).

website of the 'Integrated System of Disasters Information' (https://s2id.mi.gov.br/). Socioeconomic data on the number and income of extremely poor, very poor and poor people were extracted from the Human Development Atlas (http://atlasbrasil.org.br). The FGT poverty measure of the potential disaster-prone areas is depicted in Figure 9. Notice that 'SC' (Santa Catarina) exhibits the best FGT (0.082), while 'MA' (Maranhao) state exhibits the worst FGT (0.495). This difference is primarily explained by the number of extremely poor, very poor and poor people of these two states. For example, 22.5 per cent of people in 'MA' are considered extremely poor, but only 1.01 per cent of people in 'SC' live in extreme poverty. Overall, the coefficient of variation[9] of the FGTs given in Figure 7 is 42 per cent, confirming that poverty gap levels are very dispersed around the mean value of 0.296.

5 Insights and discussion

In order to understand how the vulnerability-driven optimisation approaches work, we conducted several computational simulations, which correspond to numerically solving through an optimisation method the models presented in the previous sections. The computational analysis of our two vulnerability-driven optimisation approaches was delineated to answer the following research questions: (1) Do the proposed approaches really improve the allocation of scarce resources of more vulnerable areas? If so, how? (2) How do the proposed approaches trade-off important

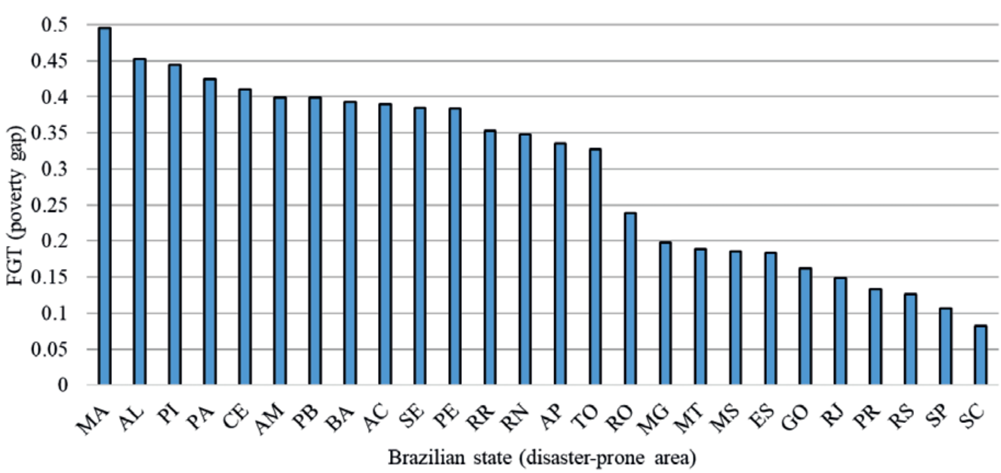

Figure 9. FGT poverty measure (poverty gap) of the 26 Brazilian states whose capitals were considered as potential disaster-prone areas.

[9] The *coefficient of variation* is the *ratio* between the population standard deviation and the population mean. Higher coefficients of variation reveal more dispersed data around the mean.

metrics, such as effectiveness and equity? For this purpose, all models were vis-à-vis compared to their versions with no vulnerability-based criterion using the performance metric called *relief service-level*, which is the percentage of needs that is actually delivered (served) within the time frame of the humanitarian logistics operation.

Figures 10 and 11 show the relief service-levels that can be obtained through the optimisation of our disaster preparedness and capacity-building response problem (i.e. 'Experience 1' illustrated in Figure 4) considering both approaches 'SoVI' (vulnerability-driven approach) and 'No SoVI' (without the vulnerability-driven component).[10] We optimised our problem assuming that there was either a 60 per cent budget cut to perform the HLOs (Figure 10) or an 80 per cent budget cut to perform the HLOs (Figure 10). This assumption is aligned with the motivation of using the vulnerability-driven approach to prioritising the allocation of humanitarian assistance when resources are rather limited.[11] Both figures exhibit the disaster-prone areas (horizontal axis) in descending order of vulnerability: from the most vulnerable ('Sudeste Rio-Grandense') to the least vulnerable ('Centro Fluminense'). The

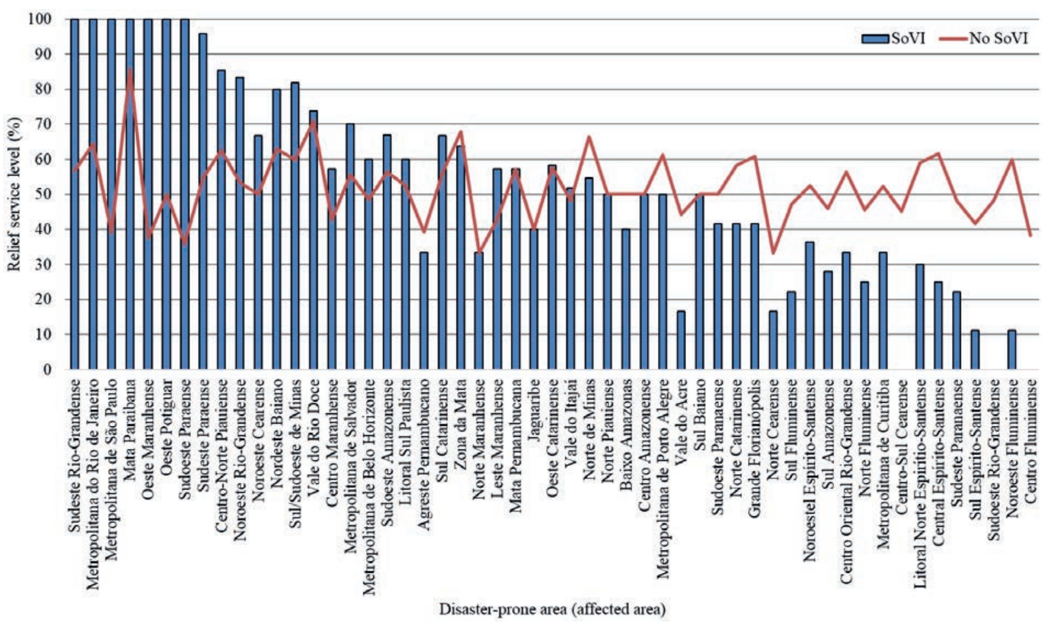

Figure 10. Relief service-level of 'Experience 1' assuming budget cuts up to 60 per cent.

[10] In this case, we set V_a to 1 in expression (1) for all disaster-prone areas.

[11] Indeed, if 'disaster resources' necessary to perform HLOs are widely available, one can claim our approach is unnecessary. Ultimately, it suffices to serve all disaster-prone areas, from the most to the least vulnerable.

results reveal that the then most vulnerable disaster-prone areas would be able to receive most of their needs for relief aid goods; in particular, the seven most vulnerable areas have 100 per cent of their needs served by humanitarian assistance (Figure 10). It is important to mention that this remarkable result is achieved at expense of the drop in the service levels of the least vulnerable areas, as the right-side of the figures suggests. As expected, when the vulnerability is neglected, relief service-levels are not driven by SoVI, and therefore, we cannot expect that more vulnerable areas present higher relief service-levels.

Indeed, the relief service-levels of 'Sudeste Rio-Grandense' are 100 per cent (SoVI) and 57 per cent (No SoVI) when budget cuts are up to 60 per cent (Figure 10), and 72 per cent (SoVI) and 27 per cent (No SoVI) when budget cuts are up to 80 per cent (Figure 11). On the other hand, 'Central Espírito-Santense' exhibits relief service-levels of 25 per cent (SoVI) and 62 per cent (No SoVI) when budget cuts are up to 60 per cent (Figure 10), and 24 per cent (SoVI) and 33 per cent (No SoVI) when budget cuts are up to 80 per cent (Figure 11). When vulnerability is not part of the decision-making process for allocation of relief aid goods, we might have allocation strategies that end up prioritising much less vulnerable disaster-prone areas as our figures reveal: the 'Non SoVI' approach allocated 9 per cent (resp. 22 per cent) more relief aid goods for 'Central Espírito-Santense' for budget cuts up to 60 per cent (resp. 80 per cent). Obviously the practice of decision-making in disaster management settings is more complex and may entail other components overlooked by our optimisation models, which could change the way allocation of relief aid goods is done. The moral of the story, though, is that our vulnerability-driven approach shows that it is possible to

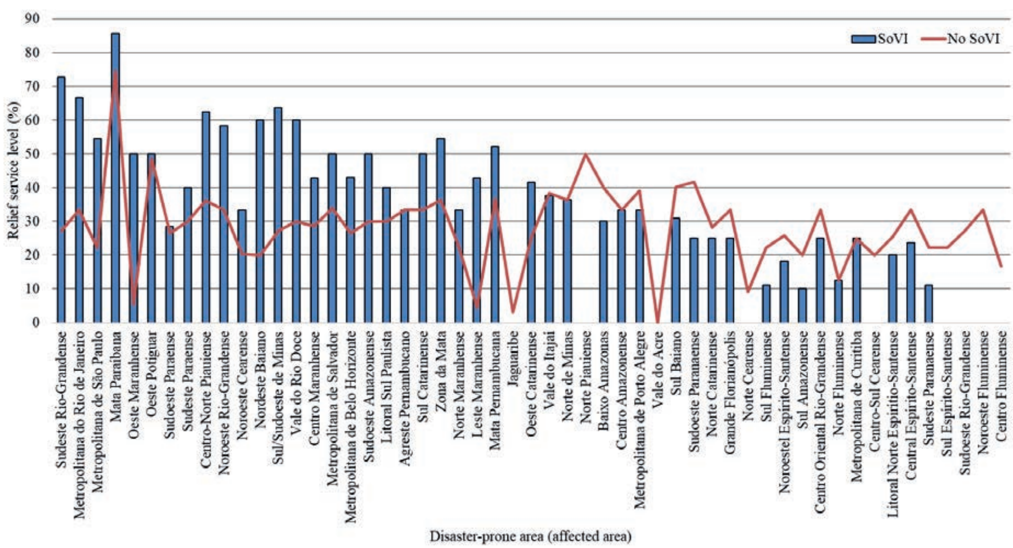

Figure 11. Relief service-level of 'Experience 1' assuming budget cuts up to 80 per cent.

factor social vulnerability into decision-making of distribution humanitarian aid, for example, thus somehow favouring more vulnerable areas in receiving aid when it is impossible to serve all disaster-prone areas due to the lack of overall resources.

Figure 12 depicts the frequency in which disaster-prone areas were prioritised over ten simulation runs[12] of our disaster preparedness and designing of prepositioning strategies (i.e. 'Experience 2' illustrated in Figure 8), starting (clockwise) from the most vulnerable disaster-prone area ('MA') to the least one ('SC').

We can clearly see that the prioritisation policy is heavily driven by the vulnerability of the disaster-prone areas, which is given by the FGT poverty measure captured by the first term of expression (2). The 15 most vulnerable areas were prioritised at least once, and seven out of the ten most vulnerable areas 'MA', 'AL', 'PI', 'PA', 'PB', 'AC' and 'SE' were prioritised in the ten simulation runs, i.e., regardless the budget cut level. Here, we assume that the types of natural hazards we want to protect people from are relatively *predictable*,[13] which is the case of several water-related natural

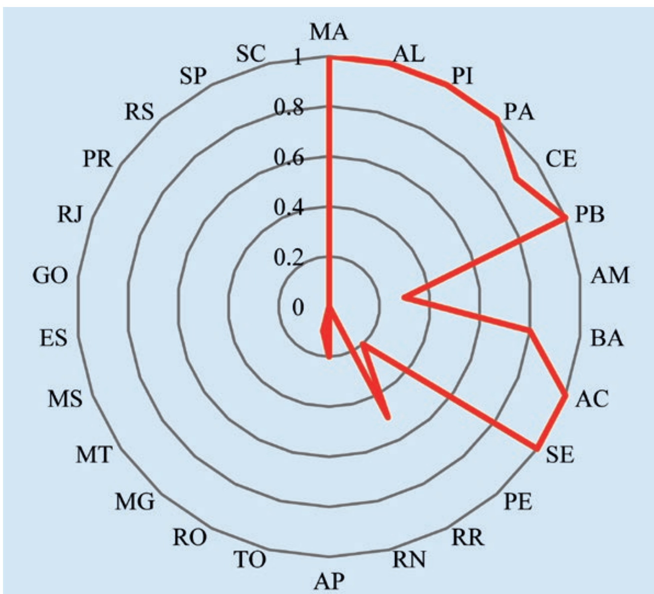

Figure 12. Frequency in which disaster-prone areas were prioritised over ten simulations ('Experience 2').

[12] Each simulation run corresponds to solving the optimisation model described in Figure 7 for a given level of budget cut. This way, in simulation run 1, no budget cut is imposed; simulation run 2 corresponds to a 10 per cent budget cut, and so forth.

[13] Assuming predictable natural hazards, it makes sense to define a disaster *timeline* to position logistics activities that must be performed in anticipation of the hazard (or *before disaster strikes* in accordance with the humanitarian logistics literature) and in its aftermath. This helps social and political bodies involved in the country's disaster management to better action towards disaster threats and risks.

hazards in Brazil, the so-called *recurrent events*.[14] Therefore, in terms of practical interventions, our results mean that the prioritisation could be done any moment during the preparedness phase even with partial (or no) information about the potential recurrent hazard *per se* and overall resources that could be destined to mitigate it because the disaster-prone areas that deserve especial attention are relatively *robust* in the face of context variation. This would allow policymakers to focus their attention and resources to those areas and the deployment of humanitarian assistance to more vulnerable communities within the critical hours of the disaster aftermath could be eased and more effective. Interestingly, Hallegatte *et al.* (2016) found out that poor people are more severely affected by *recurrent* events, and described three case studies showing this alarming result:

> *Large-scale events make the news, but repeated small adverse events such as regular floods often have serious implications for poor people, even though little data exist on them and their consequences. And although poor and nonpoor people may decide to live in places that are sometimes affected by natural hazards—to enjoy other benefits—only poor people live in dwellings that are frequently flooded or in areas in which landslides are common. (p. 40)*

If recurrent hazards affect (more often) poor people (in a given geographical area), and data can help us to identify who is (more) at-risk in the imminence of natural hazards, our vulnerability-driven approach can help not only the formulation and implementation of other preparedness and response activities (as shown in Table 1), such as public education and awareness campaigns, but also contribute to more strategic goals of 'building the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters', 'creating sound policy frameworks at the national, regional and international levels, based on pro-poor and gender-sensitive development strategies, to support accelerated investment in poverty eradication actions', 'significantly reducing the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations', which are all part of Sustainable Development Goals defined by the United Nations.[15]

[14] Recurrent events may repeat themselves year after year and are mostly associated to certain climatological triggering circumstances that often occur in specific seasons. For example, the analysis of past data on natural hazards occurred in Rio de Janeiro State from to 2003 to 2016 show that many types of hazards, such as floods and landslides, occur more often during warmer months, from November to April.

[15] The 2030 Agenda for Sustainable Development was adopted by all United Nations Member States in 2015; see more at www.un.org/sustainabledevelopment/

6 Concluding remarks

Approaching the optimisation of humanitarian logistics operations from the social vulnerability viewpoint, putting the reality of the most vulnerable first in humanitarian logistics efforts, has the main purpose of giving visibility to the invisibilised population that is by far more affected by natural hazards and suffer the most with its consequences. This article has examined two experiences on decision-making in humanitarian logistics that have developed vulnerability-driven optimisation approaches whose underlying idea is to have a vulnerability-based criterion embedded in a mathematical programming model in which the ultimate goal is the allocation of scarce humanitarian assistance. Differently from the mainstream literature in which overall logistics decisions are somehow monetary-based,[16] or disregard the population's vulnerability, in the vulnerability-driven approach, resource allocation is strongly based on the vulnerability profile of the population of a given disaster-prone area. The first experience focuses on disaster preparedness and capacity-building response problem using the Social Vulnerability Index, or SoVI, whose corresponding objective encourages fulfil victims' needs of more vulnerable disaster-prone areas over less vulnerable ones, aligned with several scholars who show that SoVI can help identify the most vulnerable, which in turn may enhance resource allocation policies during the disaster lifecycle. SoVI is widely accepted and used in different contexts and applications; and it is fairly robust and can be 'easily' replicated. The second experience relies on a disaster preparedness and designing of prepositioning problem in which the FGT poverty measure is used as the main vulnerability proxy. For this purpose, several aspects of the sociology of disasters were brought together, specifically those that make the claim that poverty contributes to vulnerability through narrowing of coping and resistance strategies, the loss of diversification and the restriction of entitlements, and the lack of empowerment. Vulnerability, in turn, weakens the ability to overcome poverty, thereby creating a vicious cycle. FGT is adapted from the popular class of poverty measures called Foster-Greer-Thorbecke, which is considered simple and satisfies desirable axiomatic properties.

The most striking aspect of the findings reported in this article is in the difference between the relief service-levels of vulnerable communities with and without the vulnerability-based criterion (SoVI and FGT) driving the logistics decisions. In this regard, the results revealed that the SoVI strategy improves the relief service-level of most disaster-prone areas at the expense of a *certain* deterioration of that of the remaining ones. FGT helps to prioritise the poorest areas and this decision is

[16] By *monetary-based* we mean optimisation models for humanitarian logistics in which the main objective relies on minimising overall costs, such as location-allocation costs or even *deprivation* costs when human life is somehow monetarised.

relatively robust in the face of context variation. Remarkably, when there is very little humanitarian assistance to be allocated to several affected areas, both SoVI and FGT help us to 'make the most' out of the resources and this generally means targeting the top (5 or 10) most vulnerable areas in the injection of relief aid goods. Although both metrics, SoVI and FGT, are crucial to the understanding of how vulnerability to natural hazards are spread across the Brazilian territory, and yield similar results concerning the behaviour of the allocation strategy, FGT may be easier to understand and interpret. In addition, FGT requires fewer data to be evaluated and, therefore, it can be more appealing in low-income countries where a comprehensively updated population census is impractical. Moreover, both metrics might be used for diverse purposes, including social monitoring, programme evaluation, and goal-setting or prioritisation. Future academic research includes analysing other vulnerability-based criteria, such as the Disaster Risk Index (DRI), as well as creating specific metrics that can be more generalisable for other optimisation problems or contexts. In addition, the implication of prioritising certain disaster-prone areas to poverty reduction and alleviation is a promising research agenda area that deserves further attention.

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Climate change driven disaster risks in Bangladesh and its journey towards resilience

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Abstract: Globally, disasters from natural and anthropogenic hazards or humanitarian crises can reverse development gains and weaken resilience. In recent years, some countries have made significant progress towards building resilience to disaster risks, including those driven by the climate crisis. Bangladesh is a leading example as it is well-known as one of the most vulnerable countries for its multifaceted hazard risks projected to intensity under climate change. Today, the scale of loss of human life from both rapid and slow-onset disasters (e.g. cyclone, flood and drought) is significantly lower than in the 1970s. This remarkable achievement was made possible by independence and the government's proactive investment in development and societal changes through education, technologies and reduction in poverty and inequalities. However, the climate crisis is threatening these development and disaster risk reduction gains. In addition, disaster displacement is a major challenge. The COVID-19 pandemic has unveiled both strengths and weaknesses in our societies. The article argues that disaster management plans need to adapt to the climate crisis and human displacement and reduce migrants' vulnerability while responding to infectious disease transmission.

Keywords: natural hazards, climate change, disaster risk reduction, resilience, sustainable development, human displacement, Bangladesh.

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Introduction

In recent decades, climate-related disasters and extreme weather events (e.g. heavy rainfall, floods, cyclones and droughts) have increased in frequency, intensity and severity driven by anthropogenic warming of the earth's atmosphere and oceans (WMO 2021). Hazards, either natural, biological, technological or anthropogenic in origin, can trigger disasters and dramatically expose the vulnerabilities within which people live in our societies (Kelman 2020). Disaster vulnerability sits at the intersection of poverty, lack of awareness and political instability (Ahmed *et al.* 2019). Disasters in low- and middle-income countries can set back hard-won development gains for a generation (Davis & Alexander 2015) while exacerbating pre-existing trends of economic migration from rural to urban areas and internationally (Mbaye 2017).

The 2021 UN Climate Change Conference (COP26) to be held in the UK aims to secure an agreement for global net-zero by mid-century and keep the 1.5°C global warming limit within reach, making the Paris Agreement operation ratified in 2016 (COP26 2021). However, the Climate Action Tracker shows that most governments' targets and actions remain highly or critically insufficient to keep to this limit (CAT 2021). Besides, scientists strongly argued that human-induced global heating is responsible for increases in both slow-onset hazards, including temperature rise, drought, sea-level rise, river erosion and land and water salinisation. It also increases the frequency and intensity of rapid-onset hazards such as tropical cyclones, thunderstorms, coastal storm surges, heavy rainfall, floods, landslides and extreme heat (NASA 2020).

It is evident that in a warmer world where the global average temperature in 2020 was 1.2°C above the pre-industrial period, adverse impacts are already being felt in the form of increased frequency of extreme weather events (UNDRR 2020). But the effects of climate change are not evenly experienced around the world. Due to its high population density and exposure, South Asia is one of the regions most exposed and vulnerable to climate and hydro-meteorological hazard risks (WMO 2021). Sea-level rise increases disaster risk for coastal communities in the Asian mega-deltas such as the Bengal Delta of Bangladesh, where more than 10 per cent of the country's population are exposed to potential inundation from coastal flooding (Kulp & Strauss 2019). In addition, coastal inundation/erosion can drive human displacement and migration within and outside the country (Chen & Mueller 2018).

This article aims to address how global warming will exacerbate disaster risks in a vulnerable region within the Global South and have the potential to drive human displacement. It is through disasters that many people will experience global climate change. Disaster risks coalesce three components: the hazard risk, exposure to the hazard, and vulnerability (Alexander 2018). The capacity to cope is a component mitigating the disaster risk. In contrast, resilience is the inverse of vulnerability. However, a paradigm shift occurred when vulnerability and exposure became the most significant components of disaster risk rather than the environmental hazard itself (O'Keefe *et al.* 1976). We work with the hypothesis that the lack of resilience, poor capacity to cope and inadequate response, coupled with power differentials and resources inequity, ultimately leads to disasters.

This review article will focus on Bangladesh—a low-lying deltaic country in South Asia, criss-crossed by hundreds of rivers. During the monsoon season (May to October), approximately 80 per cent or more of the rainfall falls, and there is little or no rainfall for the rest of the year. Due to its sub-tropical geographic position and extremely flat landscape, Bangladesh is exposed to a wide array of natural hazards and is well-known globally for its frequent disasters. Bangladesh has six major distinct disaster-prone regions according to the National Plan for Disaster Management (NPDM 2021): the coastal zone (19 per cent of the total land area), Barind and drought-prone areas (15 per cent), wetland ecosystem (also known as *Haor*) and flash flood areas (11 per cent), Chittagong Hill Tracts and landslide hazard (9 per cent), river system and estuaries (24 per cent) and urban areas (13 per cent). However, only 8 per cent of the country's total area has been categorised as relatively less hazard-prone (GED 2018).

Bangladesh has a population of approximately 166 million and one of the world's highest population densities (about 1,200 people per km^2). It has high levels of poverty (World Bank 2021). Bangladesh is considered one of the most vulnerable countries to climate change and associated natural hazard-induced disasters (Eckstein *et al.* 2021). Furthermore, disaster displacement is an emerging threat. This article examines how Bangladesh has made significant progress in disaster risk reduction (DRR) over the last 50 years since its independence in 1971. Global warming can jeopardise these achievements when combined with other threats, such as the conflict-driven refugee crisis, pandemic and geopolitical instability. Here, we consider the hazards listed in the NPDM 2021 as critical disaster risks to achieving sustainable development. But we focus on the slow-onset hazard of sea-level rise and the climate-related rapid-onset hazards of cyclones and storm surges, floods and landslides identified as critical by HCTT (Humanitarian Coordination Task Team) Nexus Strategy for Climate-related Disasters 2021–2025 (HCTT 2021). We also examine the disaster impacts on human displacement in Bangladesh.

The article combines a desk-top study analysing data from the International Disaster Database, the Global Risk Data Platform, the Bangladesh Flood Forecasting and Warning Centre and the Bangladesh Bureau of Statistics, together with the most up-to-date national and international reports and policy documents related to climate change and disasters. After briefly placing Bangladesh in the global disaster risk context, the article describes both slow- and rapid-onset hazards impacting the country.

Lessons learnt from previous disaster events are discussed in the DRR framework and features of a resilient country and community. Next, how climate change is influencing the frequency, intensity and magnitude of hazard events is discussed. Then some new evidence on internal migration due to climate-related hazards in Bangladesh is presented. Finally, we have made recommendations for future actions in building resilience to climate-driven natural hazard risks.

Natural multi-hazard risks in Bangladesh

Globally, the number of recorded natural-hazard induced disasters has increased fivefold since the 1970s, but the total number of disaster deaths has significantly decreased (Figure 1a). Specifically, climate-related disasters and extreme weather events have increased in frequency, intensity and numbers from 3,600 in 1980–99 to 6,700 in 2000–19. Disaster deaths peaked in 1959 at over 2,000,000, while in 2010, they were under 500,000. Progress in DRR through decreasing vulnerability and exposure is attributed to causing the reduction in global disaster deaths as a proportion of the population (Bahadur & Simonet 2015). The global trends in the number of disasters caused by various natural hazards worldwide from 1950 to 2019 and human fatalities from those disaster events are shown in Figure 1a. Drought, earthquake, extreme temperature, extreme weather, floods, landslide, mass movement, volcanic activity and wildfire are all considered. Here, hazard data from the Emergency Events Database (EM-DAT) are sourced from OFDA/CRED International Disaster Database via Our World in Data (Hannah & Max 2014). Over the same period, major floods doubled from 1,400 to 3,200 while the number of storms grew from 1,500 to 2,000 (UNDRR 2020). Many of these cases are seen in China and the United States; however, they also impact low-income countries, such as Bangladesh, one of the top ten affected countries with more than 100 catastrophic disasters recorded between 2000 and 2019.

One of the consequences of hydro-meteorological disasters is human displacement. The world has seen a sharply rising trend in human displacement through cross-border migration and internal displacement, with nearly 80 million people being forcibly displaced at the end of 2019 as a result of conflicts, violence, human rights violations and disasters. This can be seen in Figure 1b, which shows the number of human displacements globally from disasters resulting from the same set of natural hazards as in Figure 1a, and conflicts and violence from 2008 to 2019. Data are taken from the Global Internal Displacement Database (GIDD), made available by the Internal Displacement Monitoring Centre (IDMC). On average, 24 million people have been displaced from 2008 to 2019, with the highest number (42 million) of displacements occurring in 2010 from natural-hazard related disasters. Natural-hazard

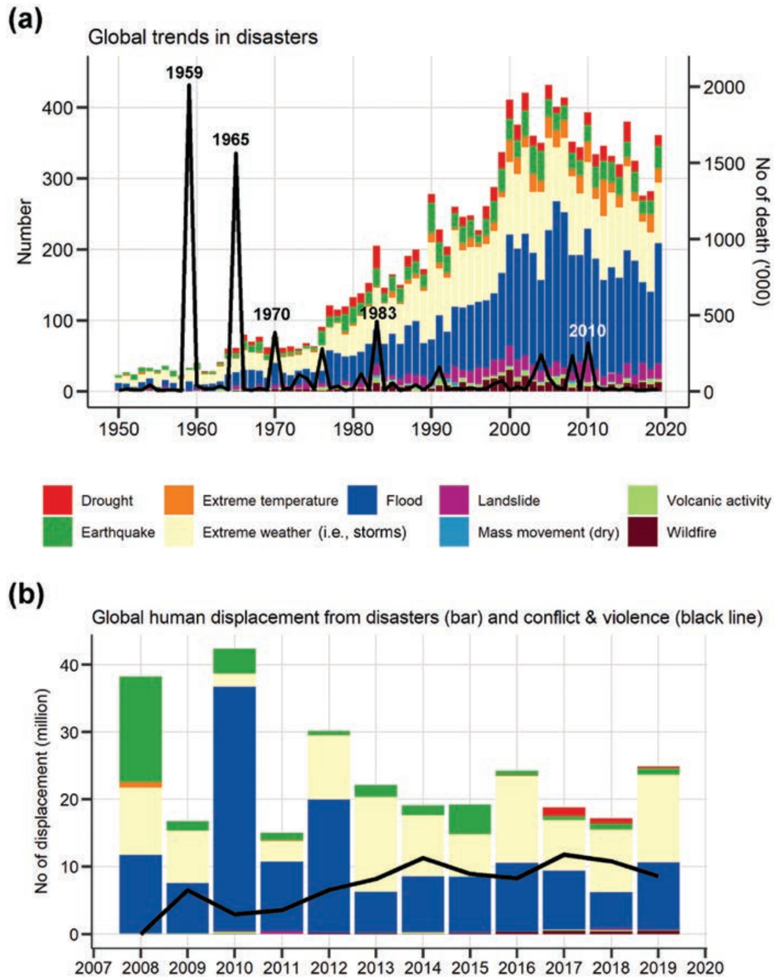

Figure 1. (a) Global trends in the number of disasters caused by various natural hazards worldwide from 1950 to 2019, along with human fatalities from those disaster events. (b) The number of human displacements globally from disasters resulting from the same set of natural hazards and conflicts and violence from 2008 to 2019. The figure legend is common for both the upper and lower panels.

displacements are principally from flooding (and coastal surges) and extreme weather. Human displacement from conflict and violence has been significantly higher in the last decade than in the previous one. In 2019, they made up a large proportion of the total displacements. For example, in coastal Bangladesh in 2020, hydro-meteorological disasters triggered 4.4 million new pre-emptive evacuations (e.g. Cyclone Amphan in May 2020). Migrants and refugee communities can be highly vulnerable to natural hazards, such as the Rohingya who fled from Myanmar to southeastern Bangladesh and face cyclones, landslides and flash-flood hazard risks (Alam *et al.* 2020a; 2020b). There may be no net migration for local disasters, where effective aid adequately compensates for the disaster losses (Paul 2005). But if there are no alternative mitigation strategies, people will migrate away from the shocks of disasters and climate change (Mbaye 2017).

Sea level rise and deltaic hazards risks

Sea-level rise is a slow-onset hazard risk that is a direct consequence of global oceanic warming and melting ice sheets. According to the Intergovernmental Panel on Climate Change (IPCC), the low-lying deltas and small islands are particularly at risk (Oppenheimer *et al.* 2019). Figure 2a shows global trends in sea levels from 1992 to 2020 in mm per year. These multi-hazard risk indices include tropical cyclones, flooding and landslide hazards induced by heavy precipitation. The figures illustrate the high and extremely high hazard risks of the South and Southeast Asian mega-deltas relative to other regions around the world but also the concentration of very high risk and extremely high risk areas within Bangladesh, the high sea-level rise of over 3mm/year and high-intensity cyclones in the Bay of Bengal.

Bangladesh's 700 km long coastline and mega-delta are highly dynamic (Brammer 2014), driven by the ever-changing nature of sea levels. Direct consequences of sea-level rise are coastal inundation and land erosion. The presence of soil, land and water salinity due to seawater intrusion in the coastal region is a vital characteristic of the low-lying deltaic environment, including the delicate coastal ecosystems of the Sundarbans mangrove forests, home to the Bengal tiger. Slowly rising sea levels have already increased the population exposure to soil, land and water salinisation and created water-logging problems and significant health hazards in coastal Bangladesh that is home to some 35 million people. While erosion impacts livelihoods and forces people to move, affected populations never enjoy economic and social stability.

Salinity hazard risks along the coast are complex as they result from both natural processes and human activities. Naturally, salinity levels in soil and surface water are generally high (greater than five parts per thousand, ppt) in the southwest coastal area relative to the eastern coast in Bangladesh (Brammer 2014). Tidal flooding by saline water occurs in the extreme southwest (i.e. close to the Sundarbans) throughout the year. Many farmers have turned their once fertile lands to brackish-water shrimp farming because they generate higher profits than cultivating rice or other cereals. This aquaculture land-use practice since the 1970s has transformed much of the farmlands into shallow, brackish water ponds.

Tropical cyclone and storm-surge hazard risks

The northern Indian Ocean contributes to nearly 7 per cent of all global tropical cyclones (Mahala *et al.* 2015). The average annual number of tropical storms in the

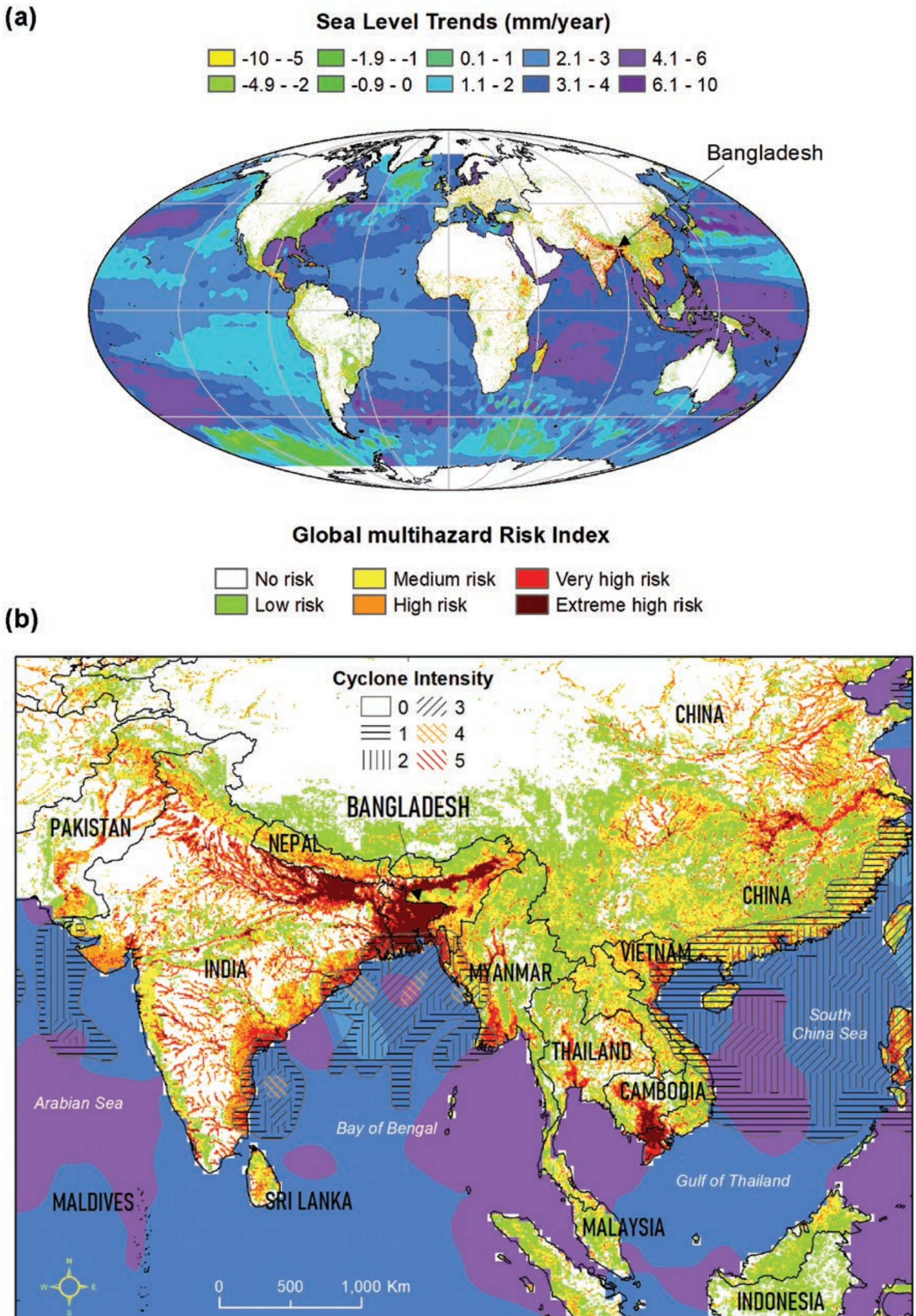

Figure 2. (a) On-ocean—global trends in sea levels from 1992 to 2020; and on-land—global multi-hazard risk indices, which include tropical cyclones, flood and landslide hazards induced by precipitation. (b) A zoomed-in map of the same features (sources: NOAA, NASA and UNEP/UNISDR).

Bay of Bengal is about 12, out of which only five can attain cyclonic strength with a wind speed often exceeding 74 mi/h or 118 km/h (Paul 2009). Tropical cyclones hit Bangladesh more or less every year though the intensity and severity of disasters and human impacts vary substantially. It is often strong storm surges, which the Bay of Bengal is highly exposed to (Figure 2), that cause the maximum damage. Table 1 lists some of the powerful cyclones that have hit Bangladesh since the 1970s and more recent ones. It is immediately apparent from Table 1 that the number of fatalities from the most recent cyclones is dramatically lower when compared to the historic Cyclone Bhola in 1970 and Cyclone Gorky in 1991.

Cyclone Bhola made landfall in November 1970. It was a Category 4 cyclone with an average wind speed between 131 and 155 mi/h (209–251 km/h) and flooded densely populated lowland plains of the Bengal delta (ESRI Storymap 2021). The loss of human lives and economic damage could have been avoided significantly if there had been sufficient preparations or evacuation plans before the event. However, just three weeks before Cyclone Bhola, a warning was given for a much smaller cyclone that hit the coast. The government (then East Pakistan) sent out evacuation orders, but the storm dissipated without causing any discernible damage. Consequently, the evacuation plans were not carried out when Cyclone Bhola was building as deploying the necessary resources were not deemed justified, which

Table 1. Major tropical cyclones in Bangladesh since the 1970s and some details on their timing and the number of deaths.

Name of cyclone	*Date*	*No. of deaths*
Cyclone Bhola	11 November 1970	300,000
Cyclone Urir Char	25 May 1985	11,069
Cyclone 04B	21 November 1988	5,708
Cyclone Gorky 1991	19 April 1991	138,000
Cyclone 1997	19 May 1997	155
Cyclone Sidr	15 November 2007	3,363
Cyclone Aila	25 May 2009	150
Cyclone Mahasen	16 May 2013	17
Cyclone Roanu	21 May 2016	26
Cyclone Mora	28 May 2017	7
Cyclone Fani	4 May 2019	12
Cyclone Amphan	25 May 2020	26

Sources: *The Independent* (2019), www.theindependentbd.com/post/223142; ReliefWeb (2021), https://reliefweb.int/country/bgd ultimately left the population exposed to the oncoming disaster (ESRI Storymap 2021). The Cyclone Bhola disaster prompted the Bangladesh Cyclone Prepared Programme in 1973 and laid the foundations for the WMO's Tropical Cyclone Programme (WMO 2020).

Nearly 20 years later, in 1991, another super cyclone (Cyclone Gorky) during a lunar high tide hit the coast of Bangladesh, killing 138,000 people. The country now had a Cyclone Preparedness Programme, cyclone early-warning system and cyclone shelters. Yet, the number of fatalities and economic damage from the cyclone was catastrophic. Khalil (1993) examined the cyclone disaster and concluded that the strong wind (recorded up to 225 km/h) and high tide favoured the exceptionally high (up to 9 m) storm surges associated with the cyclone and that the storm surges almost exclusively caused the human casualties. In addition, the study found that a majority of the residents did not want to evacuate even though they received warnings about the cyclone. But early warning information about the cyclone and the floods was transmitted by men to men in public spaces, rarely reaching women directly and in part explaining why five times more women than men died (Ikeda 1995). The consequences can be significant when warning systems do not consider gender differences, as the 1991 Bangladesh Cyclone demonstrated.

In contrast, Cyclone Sidr in 2007, despite being a superstorm, took fewer lives (3,363), although it caused substantial economic losses totalling nearly USD 1.7 billion (Paul 2009) because of successful warning and evacuation. The storm surge associated with Cyclone Aila in 2009 displaced almost 1 million people, destroyed 175,000 homes and rice farmland (Higgins *et al.* 2014) but took much fewer lives (150). Cyclone Amphan, which made landfall on 20 May 2020, displaced 2.5 million people (WMO 2021), inundated over 400,000 hectares of land and damaged rural households but claimed few lives (26). Provision of a timely cyclone forecast, an effective early warning and successful evacuation of coastal residents are all factors behind the reduction in the death toll (Kelman *et al.* 2018). However, cyclone shelters are not available to the over one million Rohingya refugees currently living in south-eastern Bangladesh. The Rohingya mostly live under bamboo and polythene sheeting temporary structures, which are highly vulnerable to cyclone hazards (Zaman *et al.* 2020).

Rainfall-triggered flood and landslide hazard risks

Bangladesh has the world's largest river network with a total number of nearly 700 rivers. The major river floodplains and regional depressions are the most flood-prone areas, and floods affect 20–25 per cent of the country every year. These are shown in Figure 3 for rapid-onset hydro-meteorological hazard risks: flash floods, river floods, tidal surges and river erosion, and graded for the level of risk. The southern and northern hilly terrains and regional depressions are prone to flash floods in the early part of the monsoon season.

Catastrophic flooding occurred in Bangladesh in 1974, 1987, 1988, 1998, 2004, 2007, 2017 and 2020. Figure 4 shows the percentage of flood-affected areas from 1954 to 2020. Data is sourced from the Bangladesh Flood Forecasting and Warning Centre (FFWC; www.ffwc.gov.bd/). The flood-affected area in Bangladesh is highly

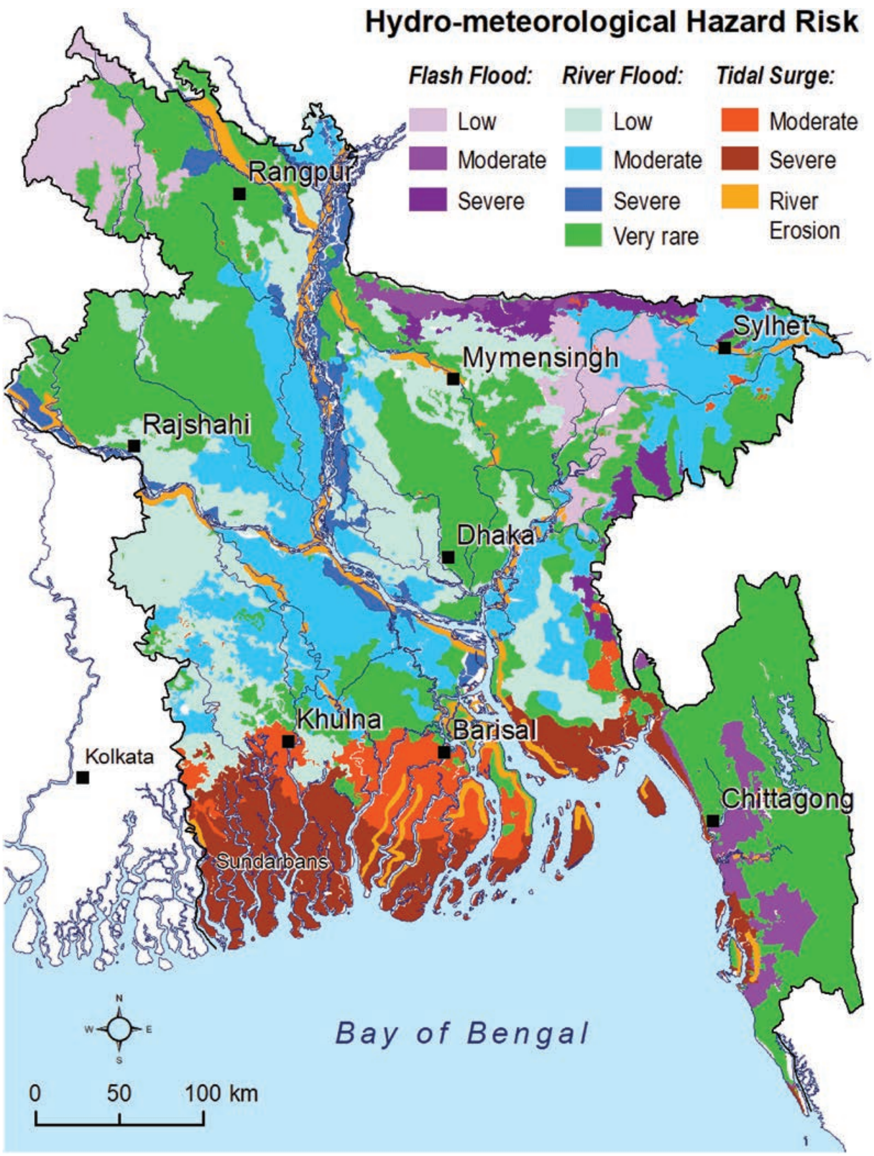

Figure 3. National-scale map showing rapid-onset groups of hydro-meteorological (e.g. flash floods, river floods, tidal surges, and river erosion) hazard risks.

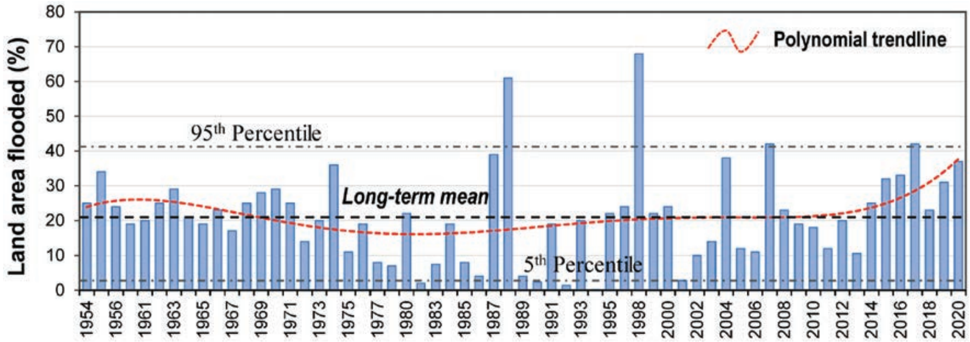

Figure 4. Flood-affected area in Bangladesh (total area: 147,570 km^2) for the period of 1954 to 2020. The long-term (1954–2020) polynomial trendline is plotted.

variable around a long-term mean value of 20 per cent of the total land area. Except for 1988 and 1998, the flooded area is generally below 40 per cent of the land area. The long-term (1954–2020) polynomial trend suggests that there is an upward trend. Some 1,050 people died, 30 million people were affected, and 25 million people were made homeless in the 1998 catastrophic flood disaster in Bangladesh (statistics from ReliefWeb; https://reliefweb.int/). A total of 251 people died in the most recent flood in 2020 that affected nearly 37 per cent of the country in two separate waves that stretched the flood season well into August.

Related to flooding is river erosion which is a flood-related hazard risk. It is often river erosion during the monsoon season that triggers disaster in floodplain communities on short timescales. River erosion is commonly observed along the banks of the major river channels in the country (Figure 3a). For example, statistics show that nearly 57 km^2 of land was lost along the right bank of the River Ganges, whereas around 59 km^2 was gained along the left bank during the 1973–2011 period (Dewan *et al.* 2017). People living along the riverbanks are part of the most vulnerable communities in the River Ganges floodplain, and their fate is primarily regulated by the dynamic nature of the river (Bhuiyan *et al.* 2017). Over the longer term, river erosion triggers human displacement and internal migration.

At present, landslides constitute a significant threat to the hilly communities in Bangladesh. Landslides are particularly prevalent in the southeastern Chittagong Hill Districts during the monsoon season. The primary driver for landslides is extreme rainfall events (i.e. greater than 200 mm in five consecutive days). But landslide disasters result from complex socio-economic vulnerabilities and physical susceptibility to landslides and hazards in the region. The root causes of landslide vulnerability in the region were identified as hill cutting and deforestation for housing development, Rohingya refugee influx, lack of institutional transparency, dysfunctional urban planning measures, settler Bengali versus indigenous tribal community conflicts and absence of an effective landslide early warning system (Ahmed 2021b).

Reduction of disaster risks in Bangladesh

The population of Bangladesh has increased steadily over the decades—although its current annual growth rate has dropped to 1 per cent (United Nations, Population Division). Since 1970, the year of Cyclone Bhola, its population has increased from 64 million to 80 million in 1980, to 128 million in 2000, to the current population of 166 million; while population density has increased from 493 to 612, to 981 to 1,265 people per km^2 respectively. So, the exposure to hazards risks could have increased severely over this time. But, as shown above, the number of deaths from hazard events has fallen equally dramatically over that period. Over this time, the average life expectancy has noticeably increased from 47 years in 1971 to 75 years in 2019 for women and from 46 years to 71 years for men (https://data.worldbank.org/). At the same time, gross domestic product (GDP) has increased from USD 4.3 to 324.2 billion at constant prices. GDP per capita on a purchasing power basis has grown from USD 1,518 to 4,181. Significant progress has also been made in poverty reduction: the poverty rate dropped to 20.5 per cent in 2019 from 23 per cent in 2016 and 49 per cent in 2000. Poverty is considered a key element in determining vulnerability to climate change (Hallegatte *et al.* 2015; Jones *et al.* 2021) because the climate crisis is regarded as a vulnerability multiplier.

Two economic sectors, in particular, contributed to this spectacular performance: Bangladesh's textile industry, accounting for 83 per cent of its total export revenues of $30 billion; and the agricultural sector, which employs over 40 per cent of the workforce, which went through a 'Green Revolution'. Women's employment in the ready-made garment sector (about 60 per cent of garment workers are female) has played a significant role in supporting their livelihoods and empowering them (ILO 2020), even if it has increased women's vulnerability when factories are poorly constructed and maintained.

In the drought-prone northwestern Barind tract region, millions of people died in devastating famines in the past that were linked directly to disasters and indirectly to lack of entitlement and weak governance (Davis 2017). The famine of 1974 was one of the worst humanitarian crises that the country had faced and cost at least 26,000 human lives due to starvation (though the unofficial figures range from 80,000 to 100,000 to even over a million deaths from hunger and malnutrition) (Sen 1981). As a young nation, addressing food shortages and long-term security was a monumental task. However, Bangladesh has made remarkable progress in the four dimensions of food security: food availability, food access, food utilisation and food stability (Dev & Kabir 2020). Bangladesh has reduced death rates to zero in the Barind tract region, and poverty reduction has been significant. The farmers now produce diverse crops three to four times a year because of access to irrigation water and agricultural innovation, and they have alternative livelihood opportunities (Ahmed *et al.* 2019).

There were two main obstacles in addressing food security: (1) land ownership and (2) irrigation water supply for agriculture. Inequality and land-ownership problems date back to the British colonial period that introduced the 'Zamindari' system in 1793, ultimately abolished in 1946. The Zamindari system led to absentee landlords of the urban areas taking over the control of land in rural areas and farmers, in particular, becoming almost landless (Ali 2005). Today, land ownership and disputes still exist, but millions of smallholder farmers have collectively contributed to the journey of food-secure Bangladesh. The second critical issue was irrigation water supply, as the country was highly dependent on rainfall before the 1970s. During the Green Revolution, Bangladesh and other South and Southeast Asian countries transformed agricultural production (Hazell 2009), livelihoods and nutrition for their people. Government interventions were essential for ensuring that smallholder farmers were included in the revolution and not left behind. The fuel that drove the Green Revolution in Bangladesh was groundwater. This hidden resource is resilient to drought and climate change compared to highly seasonal and unpredictable surface water. Today, Bangladesh produces rice in approximately 40 per cent of its irrigated lands compared to 12 per cent back in the 1970s; today, nearly 80 per cent of all irrigation water supply comes from groundwater (Shamsudduha *et al.* 2020).

Since the early 1970s, Bangladesh progressively instituted disaster risk reduction (DRR) plans and legal frameworks, climate change strategies, enhanced institutional capacity, supported vulnerable communities, invested in climate-resilient infrastructure, and developed innovative digital technologies (Kazi 2020). To address cyclone hazard risks, the Bangladesh government invested in cyclone preparedness, community-based early warning systems, hydro-meteorological DRR initiatives, and adaptive delta management, combined with structural interventions. These efforts ultimately saved human lives, reduced economic losses and protected development gains (Kazi 2020). There are two crucial areas where Bangladesh has transformed cyclone and extreme weather-related exposure in the country: (1) climate-resilient infrastructure such as the construction of cyclone shelters and coastal polder embankments; and (2) development of cyclone early warning systems and evacuation plans backed by DRR education and training. In the 1970s, the country had only 42 cyclone shelters, whereas now, over 12,000 functional cyclone shelters can accommodate nearly 5 million people. However, people are still taking a 'wait-and-see' approach mainly due to the fear of losing properties (Hadi *et al.* 2021). Compared to the pre-independence state (1971), the country has invested immensely in constructing thousands of kilometres of flood-protective embankments (also known as polders) to protect the coastal population of almost 35 million who live with the high risk of sea-level rise, tidal inundation, storm surges and saline-water intrusion. However, whilst polders have protected against storm surges and fluvial-tidal events of moderate severity, they have exacerbated more frequent flooding from heavy rainfall and promoted potential flooding impacts during the most extreme storm surges (Adnan *et al.* 2019). These are consistently impacting livelihoods and critical infrastructure (Kelman & Ahmed 2020). Local people, non-governmental organisation (NGOs) and public authorities are working together to implement the indigenous tidal river management schemes and nature-based solutions to adapt to the changing climate and upstream reduction of freshwater discharge. Other initiatives include installing flood-resilient hand tube-wells, raising latrines, providing community awareness training, improving early warnings and evacuation systems, training volunteers, and promoting alternative livelihood opportunities. This is illustrated in Figure 5, where a range of livelihood options in rural, coastal regions in Bangladesh are shown, including a backyard plantation, a small village shop, an in-house clothing and tailoring business, and cattle rearing (Ahmed *et al.* 2016).

The COVID-19 pandemic has revealed fragility across high and low-income countries worldwide and highlighted how vulnerable and ill-prepared we are in tackling the global crisis. Bangladesh is not immune to the COVID-19 problem, which has caused setbacks in gains towards sustainable development. Significantly, a pandemic will also impact the response to a disaster such as a cyclone. For instance, cyclone shelters could become vehicles for the transmission of infectious diseases. While on the other

Figure 5. A range of livelihood options in the rural, coastal region in Bangladesh: (a) backyard plantation, (b) small village shop, (c) in-house clothing and tailoring business, and (d) cattle rearing (source: Ahmed *et al.* 2016).

hand, hospitalisations and demands on health care services could impact the disaster response.

Climate change, disasters and human displacement

Bangladesh is making significant progress towards reaching the UN Sustainable Development Goals (Munir 2019) and is performing well in poverty reduction, gender equality and annual GDP growth. The fact that Bangladesh is rapidly developing and has one of the highest growth rates in the world (3.79 per cent in 2020) (IMF 2021) and poverty rates which have halved in 20 years (to 20.5 per cent in 2019) (World Bank 2021) means there are natural grounds for optimism. Bangladesh is on track to achieve the first three SDGs to end poverty, hunger and improve public health. But human-induced climate change could reverse these spectacular development achievements. Overall, the combined effects of climate change could be responsible for a loss of 1–2 per cent of GDP per year in Bangladesh (GED 2018). It took centuries for the local communities and the country as a whole to reach this level. Moreover, there is a strong correlation between poverty and intensity of natural hazard exposure; 67 per cent of the top high-risk districts have poverty rates higher than the Bangladesh national average (GED 2018). Consequently, the DRR advances are also at risk.

According to the Bangladesh Delta Plan 2100 (GED 2018), it is anticipated that by 2050 there could be an increase in the intensity of tropical cyclones (i.e. a 10-year return period cyclone will be more intense and cover 17 per cent more area), and an increase in tidal storm surges and coastal floods with an inundation depth of 14–69 per cent higher than the present level. These intensified coastal hazards would accelerate human migration to urban areas within the country and beyond in the coming decades. Dasgupta *et al.* (2010) analysed the vulnerability of Bangladesh to cyclones in a changing climate, the potential damage and adaptation cost. They identified the polders, coastal populations, settlements, infrastructure and economic activity at risk of inundation. A 27 mm sea-level rise, which has since occurred, and 10 per cent intensification of wind speed, would increase the exposed zone by 69 per cent, and an estimated 59 of the 123 polders would be overtopped during storm surges. Another 5,500 cyclone shelters would be needed. The primary driver for landslides is extreme rainfall events (i.e. greater than 200 mm in five consecutive days) that are becoming more frequent due to climate change (Kirschbaum *et al.* 2020). Therefore, substantial strengthening of DRR infrastructure and early warning systems will have to be invested in continuously.

The imminent threats to food security are still present as reduced rainfall because of climate change, depletion of groundwater, and water management in the upstream countries can cause severe agricultural droughts and water scarcity (GED 2018).

Both meteorological and agricultural drought are observed from time to time as low precipitation leads to soil moisture deficit and, thus, limited crop growth in the drought-prone areas (Prodhan *et al.* 2020). Due to extreme seasonality in Bangladesh, drought-like conditions are observed, particularly in the northwestern, north-central and southwestern regions. Climatological hazard risk areas are shown in Figure 6, where slow-onset groups of climatological hazard risks (particularly drought) and climate-driven but anthropogenic hazard risks (e.g. the depletion of groundwater storage) are well-mapped. The impacts of climate change could extensively reduce rice and wheat production by 17 per cent and 61 per cent, respectively. An increasing proportion of coastal Bangladesh could experience seasonal to permanent inundation, and the increase in saltwater intrusion can negatively affect agriculture-based livelihoods and ecosystems. It is anticipated that by 2050 there may be an increase in soil salinity (18 to 24 per cent) in the entre coastal region (GED 2018).

Currently, nearly 98 per cent of the population get their drinking water from groundwater as the surface water is highly polluted. Some waterborne (e.g. diarrhoea, cholera) and vector-borne diseases (e.g. dengue, chikungunya, malaria) are likely to be intensified with climate change. Groundwater provides almost 80 per cent of all irrigation water supplies that are critically needed to produce crops, primarily the dry-season 'Boro' rice, without which Bangladesh would not have been able to achieve near self-sufficiency in food grains (Shamsudduha *et al.* 2020). This phenomenon is also true for other nations in South and Southeast Asia (e.g. India), where irrigated agriculture through the 'Green Revolution' (Hazell 2009) since the 1960s has helped countries achieve near self-sufficiency in food grains.

There is a growing concern of substantial human displacement and migration, both within the country and beyond the border, as a result of increased climate-induced environmental hazards and disasters (Hauer *et al.* 2020). The IPCC reported a strong correlation between global temperature rise and out-migration due to extreme poverty from agriculture-dependent communities (Hoegh-Guldberg *et al.* 2018). Nearly 1,900 natural hazard-induced disasters triggered around 25 million new internal displacements across 140 countries in 2019 alone. The number is three times higher than conflict and violence-related displacements, and of which approximately 24 million people were displaced solely due to extreme weather-related disasters globally (IDMC 2020). Each year since 2008, disasters forcefully displaced an average of 25 million people, and 97 per cent of them were related to climate-related disasters. Most of them originated from the least developed countries (IDMC 2020) because communities in the Global South are often less prepared due to pre-existing social inequalities, lack of access to advanced technologies and limited ability to adapt to the changing climate. That might trigger displacement and human migration through sustained economic losses and environmental degradation.

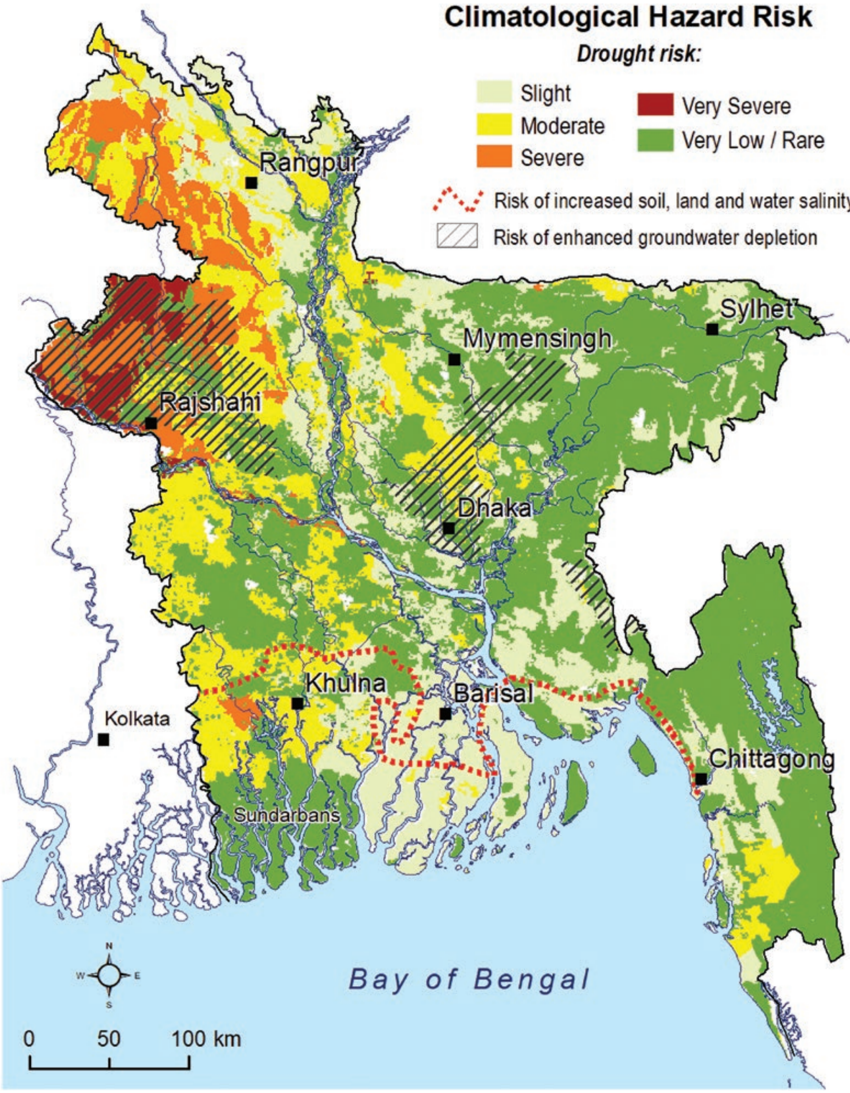

Figure 6. National-scale map of slow-onset groups of climatological (e.g. drought, soil, land and water salinisation), and climate-driven but anthropogenic (e.g. depletion of groundwater storage) hazard risks in Bangladesh.

Bangladesh has developed adaptation strategies to minimise forced displacement. However, situations arise when people need to move (Chen & Mueller 2018). For example, in 2020, the monsoon floods affected 5.4 million people, their livelihoods and their homes, resulting in homelessness and prolonged displacement for thousands of people (UNDRR 2020). Between 2001 and 2011, we calculated around 5.6 million environmental migrants in Bangladesh, of whom 2 million were climate migrants (Ahmed 2021a). These data are presented in Figure 7. The authors produced the figure in a new analysis of 337,000 national-level household survey data from the

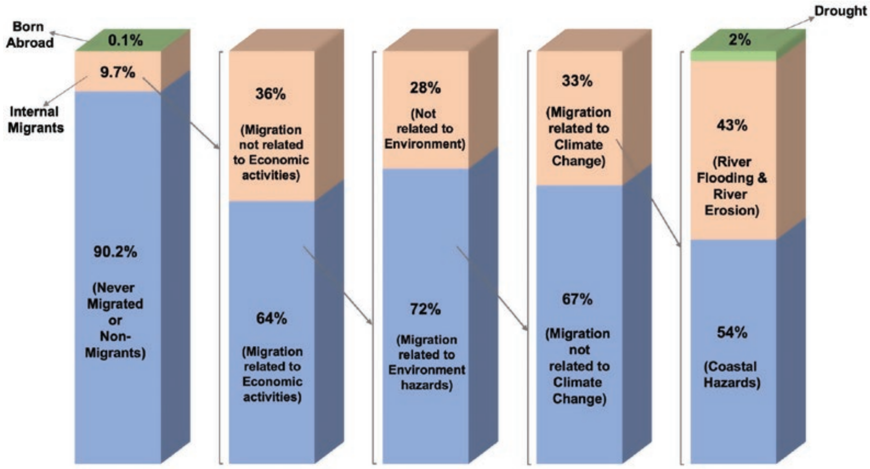

Figure 7. The distribution of economic, environmental and climate migrants in Bangladesh.

Bangladesh Bureau of Statistics (2001–11). It shows the distribution of economic, environmental, and climate migrants in Bangladesh. We found that only around 9.7 per cent of the population migrated internally, of which 64 per cent were economic migrants. Of the economic migrants, 72 per cent were environmental migrants, of whom climate change forced 33 per cent of the migrants primarily (Figure 7). The World Bank estimates the number could reach up to 13 million by 2050 (Rigaud *et al.* 2018). As a whole, climate change is aggravating other drivers of human displacement—disruption to livelihoods, agricultural activities, food insecurity, intensifying extreme poverty, freshwater scarcity, and enhanced vulnerabilities related to governance and socioeconomic factors. As a result, agriculture-dependent marginalised people are being forced to relocate to large urban areas to seek a better life. Still, they often find themselves getting trapped in poverty and insecurity (Ahmed 2021a).

Summary and recommendations

In this case study, we reviewed both rapid and slow-onset natural hazard risks in Bangladesh which are often cited as the most vulnerable country to climate change. Here, we analysed a range of hazard risks and disaster events and discussed how the country has developed economically and socially over the last 50 years and has been building its resilience to natural hazards and associated disasters. Today, fewer people die from natural-hazard related disasters in the country compared to the 1970s. It is a remarkable achievement when considering the increase in population and greater physical exposure to disaster risks.

With significant economic growth over the last 50 years, reduction in poverty, self-sufficiency in food production, infrastructure development, digital and mobile technologies (e.g. access to mobile telephones, high-speed internet) and collective social changes, the country is now much more resilient to disasters. Development of disaster risk reduction (DRR) infrastructure (e.g. coastal embankments, cyclone shelters) and early warning systems, combining technology and social education, have been crucial. These societal changes and development initiatives by the government, private sector and NGOs systematically introduce resilience to natural and anthropogenic changes in Bangladesh.

Natural hazards and associated disasters intensify due to climate change, unsustainable development, rapid urbanisation and population growth, particularly in the Global South, including Bangladesh. The COVID-19 pandemic has unveiled both strengths and weaknesses in our societies. In this highly polarised and unequal world, climate mitigation alone cannot protect millions of vulnerable people in Bangladesh who are likely to face catastrophic disasters through intensified natural hazard events. Countries like Bangladesh should focus on adaptation, technological solutions, global-scale collaboration, ongoing social transformation and enhancing their resilience to the emerging climate crisis.

Disaster management plans need to be revised dynamically to assess how to adapt them to respond during a pandemic, considering the potential for infectious disease transmission. These plans need to address specifically the need to reduce the vulnerability of refugee, internally displaced and migrant communities whose numbers are likely to increase. Furthermore, strategies need to specifically address gender responses to hazard events and warnings. There will need to be substantial and continuing investments in early warning systems and DRR infrastructure.

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Urban infrastructure, climate change, disaster and risk: lessons from the past for the future

Robin Coningham and Lisa J. Lucero

Abstract: Narratives of lost cities and the exploration of ruins have captivated scholars and travellers for hundreds of years with explanations for their demise ranging from invasions to cataclysmic environmen-tal events. This article explores three case studies to consider the impact of climate change, disaster and risk on urban infrastructure in the past, as well as to reflect on potential lessons of adaptation and resil-ience for modern cities and their inhabitants. The first examines the degree to which historic urban infra-structure can tell us about seismic adaptation in pre-modern Nepal, as well as recognising the increasing challenges to vernacular architecture from climate change. The second, Sri Lanka's Medieval cities in the North Central Province, examines the intricate relationship between the ancient city of Anuradhapura and its artificial hydraulic landscape, a relationship which saw resilience defeated by irreversibly engi-neered adaptation. The final example is drawn from the experience of another tropical society on the other side of the globe, the low-density urban Classic Maya of Central America, which offers different yet relevant insights into alternate urban lifeways, both ancient and contemporary. Focusing on issues of successful and unsuccessful adaptations in urban settings over an archaeological time range and eval-uating how archaeologists and historians have explored and presented this evidence, we conclude by considering how archaeology and archaeologists can also play a greater role in future sustainable urban planning.

Keywords: climate change, urban infrastructure, disaster, risk, reliance, adaptation, pre-modern Nepal and Sri Lanka, earthquakes, tsunamis, historic infrastructure, the Classic Maya, path dependency, lessons learned.

Notes on the authors: see end of article.

Introduction

At the conclusion of the Fourteenth Summit of the South Asian Association for Regional Cooperation (SAARC) in 2007, the Presidents of Afghanistan, the Maldives and Sri Lanka; the Chief Adviser of the Government of Bangladesh; and the Prime Ministers of Bhutan, India, Nepal and Pakistan issued a declaration in which they:

> *expressed deep concern over global climate change and the consequent rise in sea level and its impact on the lives and livelihoods in the region. They emphasised the need for assessing and managing its risks and impacts. They called for adaptation of initiatives and programmes; cooperation in early forecasting, warning and monitoring; and sharing of knowledge on consequences of climate change for pursuing a climate resilient development in South Asia. (Government of India 2007)*

Followed by an action plan two years later, their commitment to understand adaptation, mitigation and policy was reiterated by the Rt Hon. Narendra Modi, India's Prime Minister at the start of 2021, when he stated that 'India's civilizational values teach us the importance of living in harmony with nature. Our ancient scripture Yajurveda teaches us that our relationship with planet earth is that of a mother and her child. If we take care of mother earth, she will continue to nurture us. To adapt to climate change, our lifestyles must also adapt to this ideal' (Government of India 2021).

These are significant statements as the South Asian leaders represent 21 per cent of the world's population and account for US$3.67 trillion of its global economy (Figure 1). Their commitment also shows practical recognition of the long-term climatic threats facing SAARC members, which range from intensifying seasonal monsoons and droughts, sea level rise, salination, shrinking glaciers, floods and droughts in addition to short environmental shocks, such as earthquakes, landslides and tsunamis. The human cost of these threats is substantial. The Centre for Research on the Epidemiology of Disasters (CRED) has calculated that 98,660 deaths per million in India between 1994 and 2013 were directly attributable to natural disasters (2017: 27). To give an idea of the impact of a single recent disaster, the number of homes damaged by the 2015 Gorkha Earthquake has been reported as 8,300, in addition to 387 schools and 26 clinics and hospitals (CRED 2017: 34). Some of these threats are greater for some SAARC members than others. Bangladesh, for example, hosts a high population density (more than 1,209 people per square kilometre) and, in extreme years, more than two-thirds of the country can be inundated (OECD 2003: 16), leaving little opportunity for relocating populations and communities to safer locations. Indeed, during the 1998 floods, heavy rain and snowmelt in India and Nepal, and elevated tides in the Bay of Bengal, led to the inundation of 100,000 square kilometres and the displacement of 30 million people (OECD 2003: 18). In that report the Organisation for Economic Co-operation and Development (OECD) has also calculated that a one metre rise in sea level would inundate 18 per cent of Bangladesh's land mass and directly affect the livelihoods of 11 per cent of its population. Protection costs also test the state's ability to meet them as coastal defences would cost over a billion dollars, and it has been estimated that the cost of resettling 13 million people would be a further US$13 billion (OECD 2003: 19).

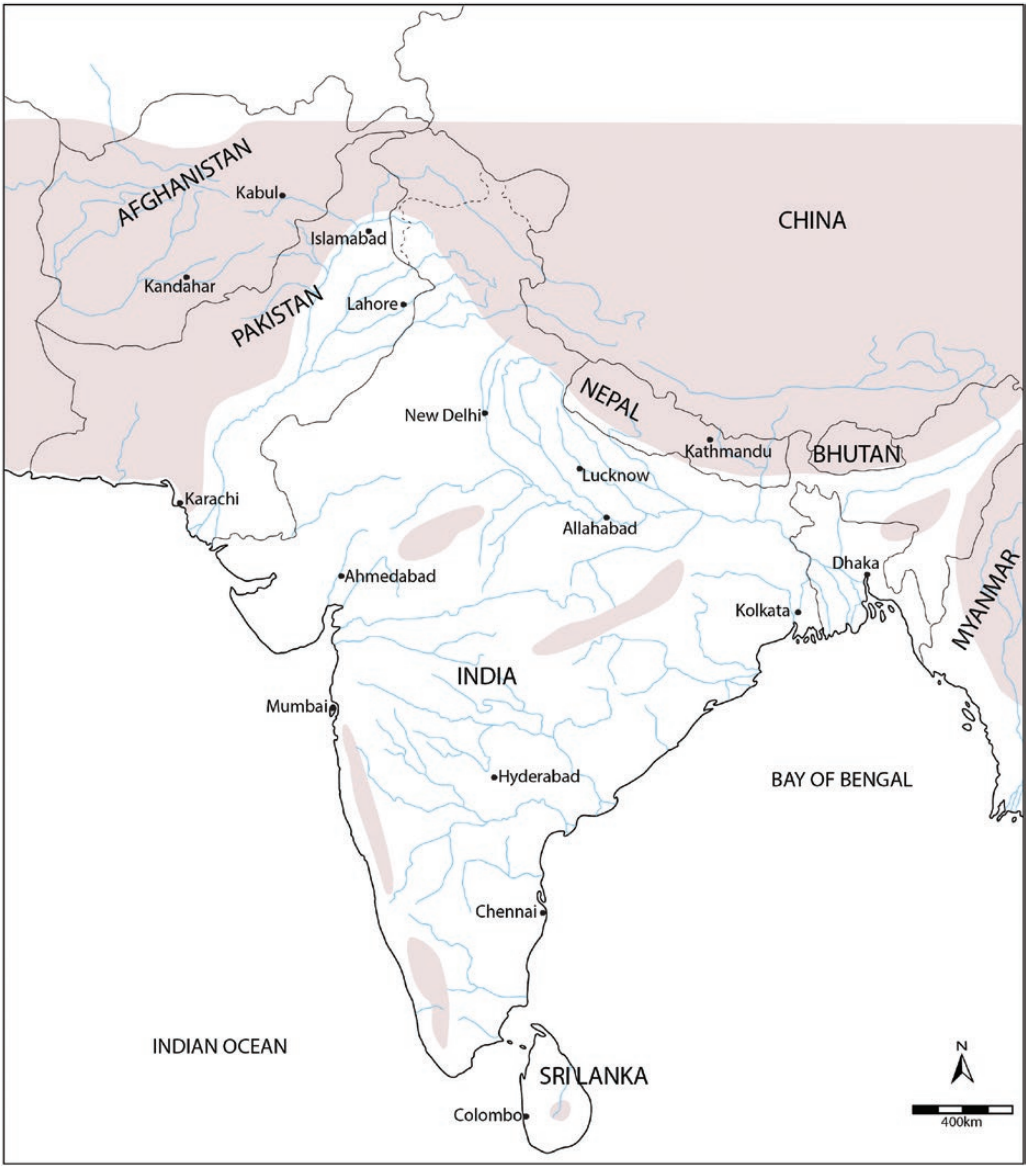

Figure 1. Map of South Asia showing modern nation states. (Image: Durham UNESCO Chair).

This brutal snapshot is shared across the globe's tropical belt, where 43 per cent of the global population resides and where 80 per cent of the world's terrestrial biodiversity is found (Harding & Penny 2020: 13) (Figure 2). However, we acknowledge that details of the exact impacts of climate change on monsoonal and cyclonic patterns and intensity are extremely complex, particularly due to the nature of the existing limited time-series and fragmentary historical records. For the purposes of this article, we have adopted the United Nations' internationally accepted definitions of climate change, disaster and risk. Article 1.2 of the United Nations Framework Convention on Climate Change (UNFCCC) refers to climate change as 'a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable periods of time' (UNFCCC 1995). Disasters are defined by the United Nations Office for Disaster Risk Reduction (UNDRR) as 'a serious disruption of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity, leading to one or more of the following: human, material, economic and environmental losses and impacts' (UNDRR 2021). Disaster risk is defined as 'The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity' (UNDRR 2021). In this article, we will focus on issues of successful and unsuccessful adaptations in urban settings over an archaeological time range and evaluate how archaeologists and historians have explored and presented this evidence, before concluding by considering how archaeology and archaeologists can also play a greater role in future urban planning.

Disasters, invasions, climate change, colonial and post-colonial histories in South Asia

In the early centuries of British colonial exploration and imperial territorial expansion across South Asia in the 18th and 19th centuries CE, scholars attributed the fall and decline of the many deserted cities, monuments and settlements they encountered directly to human intervention, favouring invasions and migrations. As such, they echoed many of the explanations offered for such phenomena within Europe at that

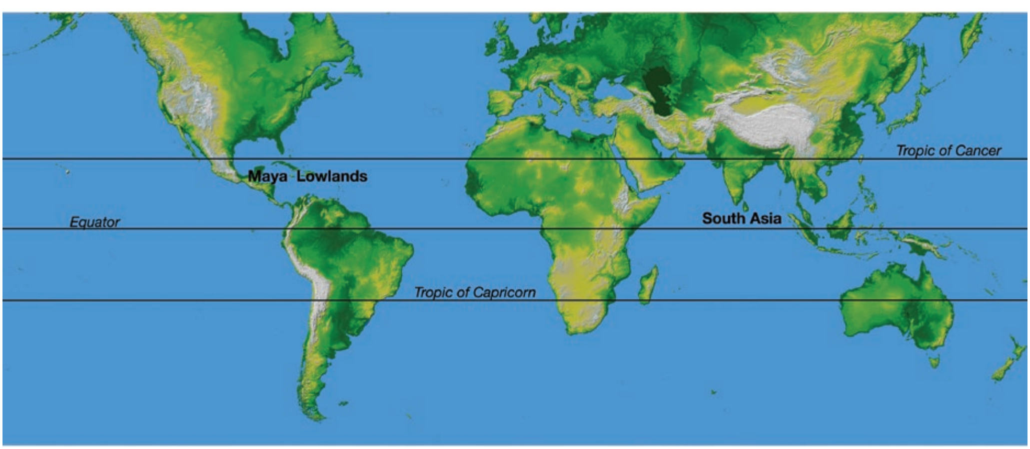

Figure 2. Map of the globe's tropical belt. (Image: L.J. Lucero).

time (Chakrabarti 2000: 667). Certainly, migration was accepted by many, including the 18th-century philologist, Sir William Jones, who suggested that similarities between most north Indian languages and those of Iran and Europe were due to the fact 'that they all preceded from some central country' (Jones 1798: 431). While we may disregard some of the more fanciful suggestions of movements of Druids across South Asia (Chakrabarti 1976: 66), such explanations soon began to encourage a reliance on concepts of cultural diffusion to assist the process of mapping cultural sequences across South Asia. As explored elsewhere (Coningham & Young 2015: 77–90), this began to promote a concept that South Asian cultural development was inherently passive until subject to external stimuli, or in the words of Mortimer Wheeler, a former Secretary of the British Academy, 'Indian prehistory … displays, like the Indian landscape, wide expanses of uniformity … But on the other hand, again like the Indian landscape, this monotony is broken by sudden changes and heights; ever and anon India leaps from its sleep and grasps new ideas, new opportunity, with quick and prehensile intelligence' (1963: 180). As a direct result, models forwarded by many archaeologists promoted external stimuli, as with D.H. Gordon's suggestion that the first cities of the Chalcolithic Indus Valley or Harappan Civilization (*c.*2600–1900 BCE) were Sumerian colonies (1960: 58), or Wheeler's own that South Asia's later Early Historic cities and states (*c.*600–185 BCE) were direct recipients of the Achaemenid Empire (1962: 13) (Figure 3). Despite rejections by a number of noted scholars at the time (Kosambi 1965: 138), many attached chronological lists of external influences within their site monographs (Marshall 1951: 83). It is also clear that these models passed quickly into common usage, as exemplified by the Christian missionary S.K. Dutta's *The Desire of India*, which stated that 'It is only when alien nations have touched the life of India that the veil is lifted and some accurate history becomes possible … By a curious coincidence the story commences, just as it closes in our own day, with a European invasion', in reference to the eastern campaigns of Alexander the Great (1909: 113).

Perhaps unsurprisingly, a similar approach was adopted when explaining the decline of those same cities and states, perhaps most forcefully again by Wheeler. Combining evidence of a mass grave, foreign weapons and the general abandonment of the cities of the Indus Civilization by 1900 BCE, he famously accused the god Indra and an invasion of Aryans (Wheeler 1966: 78). Focusing on a later period, Sir John Marshall pursued a similar explanation by attributing the decline of the famous Early Historic city of Taxila on Pakistan's portion of the Silk Road, to an invasion of Hephthalites, also known as 'White Huns', in the 5th century CE. This long-serving Director-General of the Archaeological Survey of India cited evidence of skeletons and vandalised Buddhist monasteries and shrines, commenting that 'From this disaster Taxila never recovered' (1960: 39). Such explanations were not to be limited to the mainland as invasions from South India in the 10th and 11th centuries CE

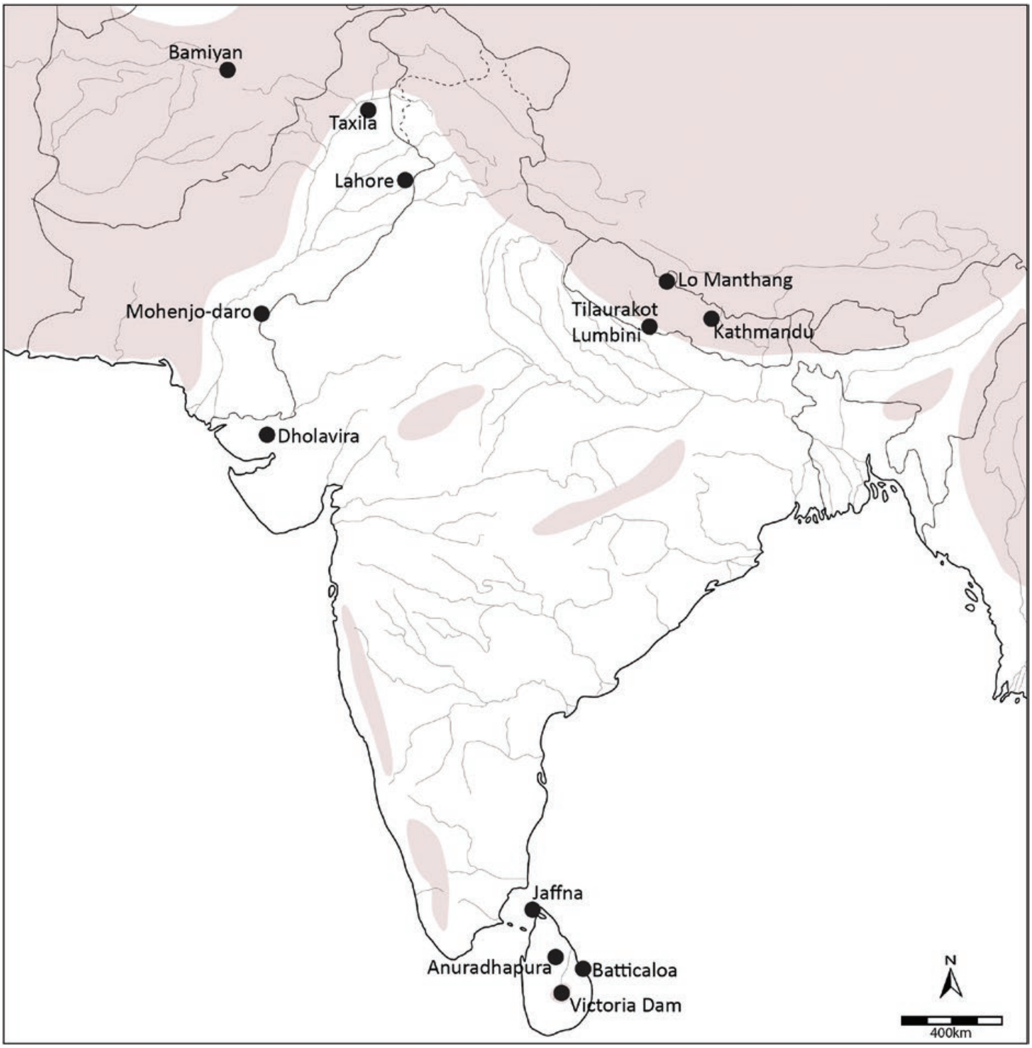

Figure 3. Map of key archaeological sites in South Asia. (Image: Durham UNESCO Chair).

were presented and accepted as explanations for the decline of the ancient capital of Anuradhapura in Sri Lanka, as well as the general abandonment of the Rajarata or 'King's Plain' around it (Codrington 1960: 94). Indeed, damaged Buddhist sculptures and monuments were frequently attributed to violence during the Chola Invasion and subsequent rule (Bell 1904: 7; Pieris 1925: 41) (Figure 4). Influenced by generations of British writers, even after the end of colonial rule (Gordon 1960: 35), explanations of cultural change through migration were also voiced by South Asian scholars in the post-colonial world (Banerjee 1965) and continue to remain popular (Seneviratna 1994: 34).

This is not, of course, to suggest that all international scholars or South Asian researchers were persuaded by such explanations. Indeed, with the increasing use of absolute chronometric dating, and the spread of processual archaeology through the 'New Archaeology' movement, many were more than willing to seek alternative explanations for the creation and destruction of cities and states. As might be anticipated, most opted to continue favouring a single prime mover but, this time, selected longer term climatic change and short environmental shocks. For example, when George Dales rejected the proposal that massacres by Aryan invasions had delivered a swift end to the Indus city of Mohenjo-daro, he proposed instead that tectonic events had led to recurrent floods, preventing its inhabitants from sowing or harvesting crops (1966). This was, in turn, countered by Lambrick, who instead suggested that avulsions and a major change in the course of the Indus River and its tributaries had resulted in the annual inundation of silt elsewhere, leading to the city's abandonment as its inhabitants sought to cultivate closer to the fresh silt, intensified by the increasing presence of salination (1967: 483). Explanations based on the impacts on short environmental shocks have continued to prove popular. For example, the end of the Indus port of Lothal in western India has been attributed to floods (Rao 1973: 59) and it has

Figure 4. View of Buddha footprints recarved with a Naga in Jaffna Museum, Sri Lanka. (Image: Durham UNESCO Chair).

been recently suggested that the walls of the Indus city of Dholavira were designed to protect it against sporadic tsunamis (Nigam *et al.* 2016: 2043). While debate still surrounds fabled cultural losses associated with the submergence of the lost continent of Lemuria in the Indian Ocean (Ramaswamy 2000: 576), there is increasing acceptance that reliance on a single factor is over-simplistic and untenable (Coningham & Young 2015: 274). Indeed, Madella & Fuller have observed that 'While many archaeologists have long argued against a climatic cause for the end of Harappan urbanism, this notion persists in some Quaternary science literature' (2006: 1298). More nuanced scenarios are now being generated, explanations which acknowledge that climatic change, resulting in a decline in rainfall, actually contributed to the emergence of urban agglomerations, as 'ever more intensive agriculture and control of surpluses, which buffered inter-annual shortfall, contributed to urban centralisation' (Madella & Fuller 2006). In that paper, the authors acknowledged that the same climatic change could also have contributed to its later decline, as 'more diversified and extensive agriculture provided strategic risk buffering for smaller, local groups and could have contributed to social changes that ultimately resulted in the restructuring of the urban Harappan social system' (Madella & Fuller 2006). A possible scenario in which a similar climate change can lead to two very different urban outcomes leaves us to conclude that, as already noted by Weiss (2016: 62), the key to societal survival lies in a community's ability to recognise the need to adapt and adjust their social and economic scaling and integration to meet longer-term trends.

Climate change, disaster risk and resilience in Nepal

As archaeology is a global discipline, these long-term theoretical trends are by no means unique to South Asia (see Middleton 2017; Diamond 2004; Tainter 1990). The present section examines the degree to which the study of historic urban infrastructure can tell us about successful historic adaptation in Nepal to an intermittent seismic environment, as well as recognising ways in which increasing challenges from climate change can be mitigated. The UNDRR has confirmed Nepal's position as the fourth in the world in terms of climate risk according to the Global Climate Risk Index as over 80 per cent of its 29 million population is exposed to earthquakes, droughts, floods, landslides, extreme temperature and glacier lake outburst floods (2019: 6). Since floods are an annual feature of the Terai in southern Nepal with devastating impacts, when designing the pilgrimage complex at the site of the Buddha's birth at Lumbini in the 1970s, Japanese architect Kenzo Tange created a circular pond levee around the site to protect the site and its visitors (Weise 2013: 133). This is not a novel phenomenon as evidence of flooding has been identified archaeologically at Lumbini's late Chalcolithic Village Mound (*c.*1300 BCE) (Strickland *et al.* 2016). Further evidence is apparent at the archaeological site of Tilaurakot-Kapilavastu, 27 kilometres to the west, where the Banganga River has clearly eroded the northwest corner of the 20 hectare walled city, which was occupied between the 8th century BCE and 1000 CE. Since then, the river has safely migrated westwards, but it is apparent that the ancient city's complex of ramparts, walls and moats played a role in mitigating the impact of flood water while benefiting from the settlement's close access to a major waterway (Davis *et al.* 2016). Settlement survey within the region has demonstrated a densely populated Early Historic landscape around the city with towns, shrines and villages, mostly clustered on fossil alluvial ridges, locations that demonstrate an awareness of the risk and mitigations (Verardi 2007: 57).

Although mitigating the impact of flooding with artificial barriers, while benefiting from the proximity of the rich agricultural landscape of the Terai, appears to have been a reasonable risk in the past, the construction of major tiered brick and timber monuments within the tectonic instability of the Kathmandu Valley seems less so. Clearly not an impact of climate change, the study of the Valley's architectural history within an extremely intermittent seismic environment provides a striking exemplar of human resilience and successful technical experimentation and adaptation. Indeed, it has been estimated that high magnitude earthquakes affect the Kathmandu Valley every hundred years or so with records of their devastation in 1224, 1255, 1260, 1344, 1408, 1681, 1767, 1823, 1833, 1834, 1869, 1916 and 1934 CE (Gautam *et al.* 2015: 1–3), making the survival of monuments over this time worthy of study. Despite their significance for lessons learned, while collateral damage to many of Kathmandu's historic structures was understandable during the emergency phase immediately following the 2015 Gorkha Earthquake as the dead and injured were recovered, professional concerns were raised that many historic structures and monuments had been irreversibly compromised and their foundations removed without recording during the subsequent clean up operations (Coningham *et al.* 2019). This destruction resulted in the loss of critical information concerning possible causes for the failure and collapse of individual buildings, as well as information concerning their successful seismic adaptation. In order to present an exemplar, a multi-disciplinary Nepali and international team drawn from the Government of Nepal's Department, the Nepal chapter of the International Council on Monuments and Sites (ICOMOS), Tribhuvan University, United Nations Educational, Scientific and Cultural Organization (UNESCO), University of Stirling, Newcastle University and Durham University's UNESCO Chair was mobilised to investigate the foundations of Kathmandu's eponymous monument, the Kasthamandap. Funding for the project's fieldwork, laboratory analysis and impact was provided by the Arts and Humanities Research Council (AHRC), UNESCO and the British Academy's Global Challenges Research Fund (GCRF) Cities and Infrastructure programme under the joint direction of Kosh Prasad Acharya and Robin Coningham, one of the present authors.

An indistinct rubble mound after the earthquake, our rescue excavations at the Kasthamandap were able to examine the development of the ancient rest house's (shelter for travellers and traders) brick foundations as well as its timber superstructure (Figure 5). Our research programme was able to establish that the monument was some 500 years older than previously thought (Slusser & Vajracharya 1974: 206) and had been initiated between the early 7th and 9th centuries CE (Coningham *et al.* 2021). This first phase comprised the construction of a massive 12 by 12 metre brick square formed by a two metre deep foundation wall set in a mud mortar, and four freestanding brick piers in the interior to support 5.6 metre high timber columns, each weighing more than a ton. Although radiocarbon dating has demonstrated that one of these original columns survived until the monument's tragic collapse in 2015, dates from the other three indicate that the monument was reconfigured and that the freestanding piers were braced by the introduction of a series of cross-walls following the apparent removal of all of the interior soil fills (Coningham *et al.* 2021). The solitary surviving wooden column was repaired and its lower tenon joint, which fitted into a stone saddlestone set above its corresponding brick pier, was replaced by a new wooden tenon dating to between the 11th and 12th centuries CE. In addition to this evidence of repair and maintenance, the new tenon was set within a copper shoe and the base of each of the four massive pillars separated from their respective saddlestones by sheets of copper. Artisans involved in the current reconstruction of the Kasthamandap have confirmed that this sheet had been purposely placed there to deteriorate as the resultant copper oxide retards both rot as well as termite infestations, indicating the strength of surviving indigenous knowledge networks (Coningham *et al.* 2019).

The interior of the monument, now comprising a nine-celled arrangement within the foundation wall, was then carefully refilled with what the project's geoarchaeologist Ian Simpson refers to as 'engineered soils' (Simpson 2021 pers. comm.), drawn from a number of very different sources (Figure 6). Subsequent analysis of the deposits by Simpson has suggested that they were purposely designed with a degree of liquefaction-proofing as they allowed the movement of water through them. Analyses of the mortars of the foundation wall also indicated that their sediment composition had a slightly raised non-swelling clay content, again indicating a degree of liquefaction-proofing (Coningham *et al.* 2019). The discovery of a nine-celled foundation at the Kasthamandap is not unique, as there have been reports of similar features within the Kathmandu Valley at Harigaon (Verardi 1988: 65). Giovanni Verardi noted that such a configuration is 'a maṇḍala subdivided into nine padas … one of the models envisaged in the traditional treatises on Newar architecture' (1988: 65). Furthermore, he recorded the

> *custom of constructing foundation walls with nine pits in a sacred building. … After the prescribed ritual, the pits are filled with sand or earth. The ritual documented … prescribes that in*

Figure 5. View of the collapsed Kasthamandap in Kathmandu after Nepal's 2015 Gorkha Earthquake. (Image: Durham UNESCO Chair).

> *each pit nine different kinds of grain are thrown. … According to another recorded ritual, it is the powder of the pañcaraṅgis, or 'five minerals' (gold, silver, copper, brass and iron) … which is thrown in the kuṇḍas. The foundation of the sacred building, conceived and laid in the above way, is then sealed with a paved floor after having been consecrated. (1988: 6)*

Figure 6. View of the nine-celled arrangement within the foundations of the Kasthamandap in Kathmandu, Nepal. (Image: Durham UNESCO Chair).

There is therefore the potential that these contemporary rites link to earlier practices of 'engineering soils' to provide a degree of liquefaction proofing; certainly there is barely any earthquake damage within the Kasthamandap's foundations (Davis *et al.* 2020).

These seismic adaptations of construction practice, combined with cycles of reconstruction and maintenance, provided a remarkable longevity for the monument of over a millennium until its collapse, an event accelerated by poor conservation interventions in the 1960s and 1970s. In addition to understanding more about historic and indigenous patterns of adaptation, renewal and maintenance, the post-disaster fieldwork also demonstrated that some of the Kathmandu Valley's environmental shocks had enabled the remodelling of urban space. For example, the currently open durbar or palace square in front of the former royal palace at Bhaktapur was once more hemmed in by structures. Following their failure, they were razed and paved over, which we were able to identify and map using Ground Penetrating Radar. Elsewhere, within Hanuman Dhoka's Durbar Square, we found evidence of levelled structures below the foundations indicating that Kathmandu's cityscapes were organic, reconfiguring over time, rather than conforming to a static plan (Coningham *et al.* 2018: 166). Indeed, earthquakes also provided opportunists the ability to appropriate monuments; our post-disaster excavations at the Jaisedewal Jaisi Deval were able to revise this structure's biography. Commonly attributed to the Minister Laksminarayana Josi in 1688 CE (Slusser 1982: 143), Optically Stimulated Luminescence dating of the monument's stepped plinths confirmed their late date, contemporary with Laksminarayana

Josi, but the solid brick temple plinth core around which they had been constructed was originally erected in the 11th century CE, built by a patron now forgotten (Davis *et al.* 2020: 741).

While the impact of the 2015 Gorkha Earthquake damaged many historic structures across the Kathmandu, the longer-term challenges to Nepal's pre-modern cities from climate change are perhaps even greater. The use of flat mud roofs on major monuments within the trans-Himalayan Valley of Mustang in northern Nepal is, for example, extremely well adapted to the valley's predominantly dry climate and seasonal snow (Figure 7). However, increasing rainfall is resulting in leakage (Selter 2007: 69). While leakage can increase the likelihood of decay, more worryingly, it can also lead to waterlogging, which adds to the weight of the roof and threatens the stability of the rammed earth walls supporting it. While some residents have reportedly experimented with plastic sheeting, this intervention often increases moisture within the structures as they cannot 'breathe' and decay accelerates, threatening the stability of the monument. Now recognised as a particular challenge to the long-term survival of this unique category of monuments within Mustang's walled city of Lo Manthang, UNESCO is working with the Oriental Cultural Heritage Sites Protection Alliance and residents, to carefully analyse the causes of the deterioration of Lo Manthang's urban infrastructure: 'namely neglect, leakage, loss of know-how in masonry and carpentry and modern materials being preferred to traditional ones' (Richon 2019: 84) (Figure 8). In this case, local masons and carpenters are involved and are 'lifting misconceptions about modern materials and raising awareness of the pertinence of local materials' features and qualities, fighting water seepage through roofs and leakage through walls'. The community is now starting to 'test, build prototypes and document the best solutions and work in the longer term with local associations' (Richon 2019: 84). Combined, these examples demonstrate the need to recognise the value of indigenous knowledge with regard to risk reduction and to acknowledge that 'Build Back Better' concept, as presented within the 2015 Sendai Framework for Disaster Risk Reduction (United Nations 2015), should not necessarily be restricted to the deployment of modern materials and technologies.

Disaster risk, adaptation and resilience in Medieval Sri Lanka

Our second case study explores the historic challenges of developing mega-infrastructure to reduce disaster risk and enhance societal resilience in Medieval Sri Lanka. As noted above, colonial-era discoveries of the damaged Buddhist statues and monuments in northern Sri Lanka were frequently identified as evidence of south Indian invasions, as exemplified by the words of H.C.P. Bell, the first Archaeological Commissioner of Ceylon:

Figure 7. View of the flat mud roofs in upper Mustang, Nepal (Image: Durham UNESCO Chair).

Figure 8. View of the rammed earth wall surrounding the city of Lo Manthang in Mustang, Nepal. (Image: Durham UNESCO Chair).

> *The indescribable confusion in which the fragments were found heaped one upon another, and the almost entire wreck of the railing, leave little room for doubt that this unique relic of Ceylon Buddhist architecture must have perished under the ruthless destruction of those invaders from*

> *South India at whose door lies the mutilation and ruin of the best works of the sculptor's art in Anuradhapura. (Bell 1904: 7)*

Many post-independence scholars also attributed the demise and abandonment of the capital, Anuradhapura, to this human agency (Seneviratna 1994: 34), drawing heavily from the narratives compiled within the island's Mediaeval Mahavamsa Chronicle: 'Thereupon they sent the Monarch and all the treasures which had fallen into their hands at once to the Cola Monarch. In the three fraternities and in all Lanka (breaking open) the relic chambers, (they carried away) many costly images of gold etc., and while they violently destroyed here and there all the monasteries, like blood-sucking yakkhas they took all the treasures of Lanka for themselves' (*Culavamsa* 1927: 55.19.22). That the city, comprising a 100 hectare residential mound known as the Citadel and 25 square kilometre sacred city core of monastic complexes, was largely abandoned by the 11th century CE is not questioned here but, rather, the explanations forwarded for its collapse (Strickland *et al.* 2018).

Before further examining the evidence for invasion, Anuradhapura's environmental setting is worthy of consideration as this massive urban complex is located in the island's Dry Zone, with an average rainfall of between 120 and 190 centimetres concentrated mainly between October and January. Adjacent to the largely seasonal river, the Malwattu Oya, the natural carrying capacity of the area is only 0.4 people per square kilometre (Coningham 1995). These stark figures provide a clear rationale for the massive human investment in the creation of a ring of large tanks or reservoirs around the city, ranging in size from the 1st century BCE Nuwarawewa, with a capacity of 42.5 million cubic metres, to the 3rd century BCE Tissawewa, with its 3.2 kilometre long dam (Coningham 1999) (Figure 9). To overcome the vagaries of localised rainfall, this system was later augmented by canals, such as the 87 kilometre long Yoda Ela, and storage tanks, such as the 2.23 square kilometre Kala Wewa, designed to tap into other headwaters. In the words of anthropologist Edmund Leach, this was 'quite unquestionably an "hydraulic society"' (1959: 9). However, Leach also noted, as a number of scholars have, that this example of mega-infrastructure existed in parallel with a simple gravity-fed cascade system of rural tanks which supported the rural population (1959: 23).

While previous British Academy funded research to the late F.R. Allchin and Coningham had defined Anuradhapura's transition from Iron Age village to Indian Ocean metropolis (Coningham 1999, 2006), little attention had been paid to the rural communities sustaining it. In order to better understand their development, a multi-disciplinary team from the Universities of Durham, Bradford, Stirling and Leicester alongside the University of Kelaniya (Sri Lanka) and the University of Baroda (India), undertook the Anuradhapura Hinterland project, an AHRC-funded survey and excavation in the surrounding region between 2004 and 2008, directed

Figure 9. View of the 4th century BCE Basawak Kulam Tank in Anuradhapura, Sri Lanka. (Image: Durham UNESCO Chair).

by Prishanta Gunawardhana and Robin Coningham (Coningham & Gunawardhana 2013) (Figure 10). Rather than finding evidence of a hierarchy of towns, villages and hamlets, as many have assumed populated the ancient landscape, the team identified a total of 754 sites forming a complex network of secular and religious heterarchies, linking the urban core and the rural hinterland. In this context, we term heterarchies as the potential simultaneous existence of multiple hierarchies (Coningham *et al.* 2007: 715), heterarchy being where 'each element possesses the potential of being unranked (relative to other elements) or ranked in a number of different ways' (Crumley 1979: 144). Indeed, there was little evidence of large-scale, secular towns in the hinterland, with Buddhist monasteries instead playing the role of administrators, centres of redistribution, and places of craft specialisation. However, it was also clear that Buddhism was not the only religion patronised within the hinterland, with the clear development of terracotta figurine cults and other practices running alongside more orthodox Buddhist monastic institutions (Coningham *et al.* 2012). These institutions, however, were clearly linked to the construction, management and maintenance of hydraulic systems that enabled agriculture to prosper and fed water to the city of Anuradhapura itself (Figure 11). This complex interchange between places of Buddhist worship, secular administration and centres of trade, termed 'Buddhist Temporalities', is unique within Early Historic South Asia (Davis & Coningham 2018), but their patterns of settlement have now been recognised as sharing similarities with other tropical forest settings in Southeast Asia (e.g. Lansing 1991) and Central America. Following

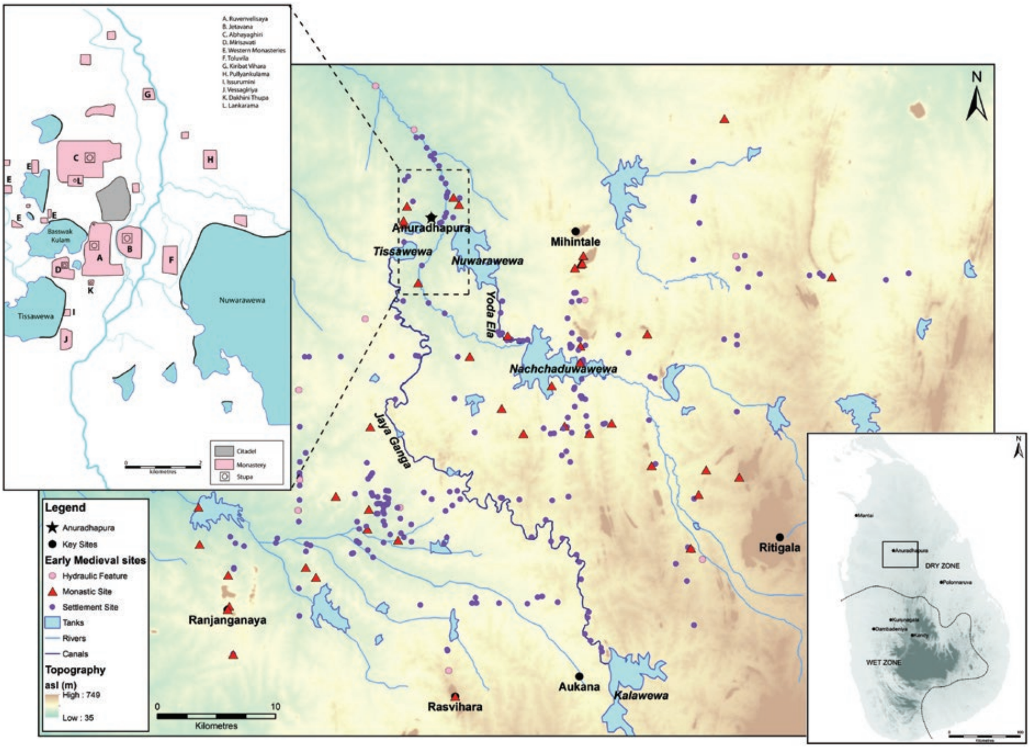

Figure 10. Map of archaeological sites identified during the Anuradhapura hinterland survey, Sri Lanka. (Image: Durham UNESCO Chair).

a Society for American Archaeology-Amerind Seminar in 2011 and a Wenner-Gren Conference in Angkor in 2012, attended by both Lucero and Coningham, we proposed the term 'low-density, dispersed agrarian urbanism' for this archaeological phenomenon in an article in the journal *Antiquity* (Lucero *et al.* 2015).

Although offering water for Anuradhapura's population, its livestock and irrigation agriculture for more than one and a half millennia, evidence for the 11th century CE decline of the city and its hinterland was also clearly identifiable. This included the abandonment of the Citadel, and smaller rural settlements, as well as evidence of the natural infill of irrigation works and water features (Gilliland *et al.* 2013: 203). This decline and lack of maintenance again can be related back to the initial function of Anuradhapura's mega-infrastructure, to provide water for people, animals and irrigation agriculture within a region where there was uneven seasonal rainfall. Undoubtedly, it also provided critical reserves for periods of drought, as well as managing surges from flash floods from cyclones and cloud bursts (Lucero *et al.* 2015: 1140). Augmented over the centuries, it was able to sustain a population as large as 200,000 (Coningham & Manuel 2009) but, once constructed, the tanks and canals necessitated massive seasonal maintenance (Scarborough & Burnside 2010).

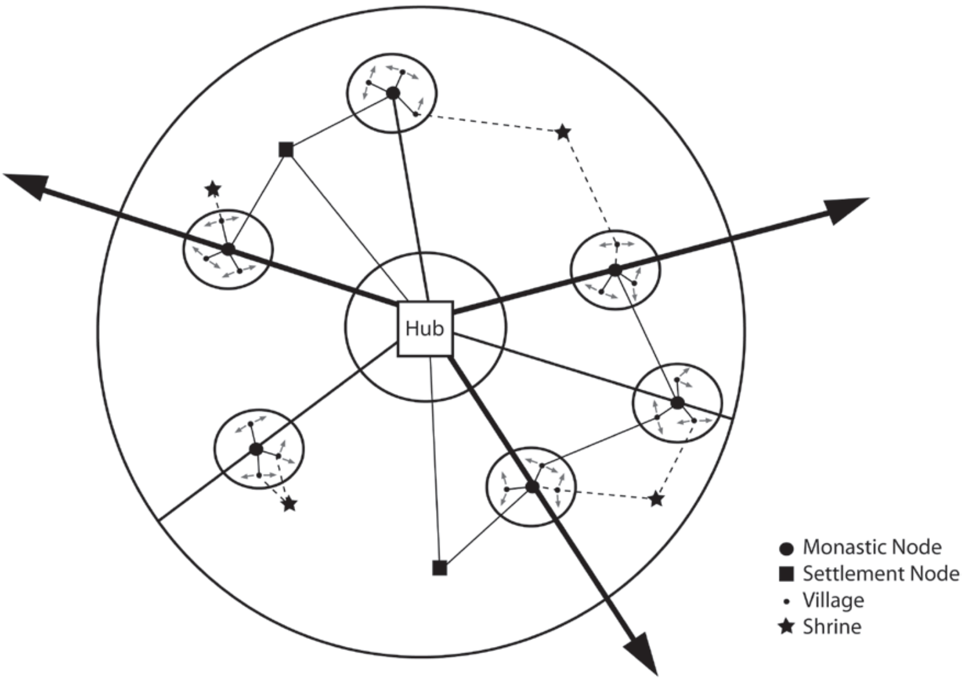

Figure 11. Schematic diagram of Anuradhapura's Medieval heterarchies, Sri Lanka. (Image: Durham UNESCO Chair).

Increasingly dependent and reliant on this configuration of 'increasingly elaborate, complex and intricately linked water systems' (Lucero *et al.* 2015: 1147), it appears that two interdependent features began to undermine its sustainability in the Early Medieval Period—access to labour and climatic instability. The first is traceable from the increasing number of inscribed stone pillars within the hinterland recording 'Immunity Grants' (Dias 2001: 113; Davis *et al.* 2013). These recorded the transfer of authority over large areas of land from royal officials to the Buddhist order but, critically, released its village communities from the traditional cycle of annual levee maintenance of royal infrastructure, including the tanks and canals which comprised the irrigation works (Gunawardana 1979: 97). This coincided with a sudden high-amplitude increase of the South West Monsoon, resulting in both severe drought and an increase in cyclonic storms within the North East Monsoon (Jung *et al.* 2004).

Whilst droughts could be mitigated through the tank and canal systems, the impact of cyclonic storms and their associated flash floods was far more challenging to manage. Indeed, a number of similar well recorded episodes within the last 50 years have demonstrated the magnitude of such impact. For example, the Batticaloa Cyclone of 1978 damaged more than 100,000 homes, killed almost 1,000 people, injured 4,500 more and damaged more than 90 per cent of the coconut crop and 60 per cent of planted rice paddies, while the 1957 storm damaged 35 major irrigation systems and

1,300 village tanks (Srisangeerthanan *et al.* 2015: 295). Whilst such catastrophes are manageable by a modern country, with associated international interventions, it is clear that such events would be beyond the resources of most ancient states. Adaptation to the challenging environment of Anuradhapura proved to be irreversible and, as noted elsewhere, 'While the interlocking systems may initially have coped with changing circumstances, including climate extremes, they eventually failed' (Lucero *et al.* 2015: 1150).

In a contemporary environment where many donor agencies prefer to focus on mega-infrastructure, accepted by many erroneously as the acme of historical irrigation development, increasing numbers of reports suggest that such large-scale interventions may not be as beneficial as previously thought. For example, between 1979 and 1985, the UK government contributed £117 million towards the construction of the Victoria Dam in Sri Lanka's Hill Country to generate hydro-electric power as well as store additional water for downstream irrigation. However, in 1992 the UK's National Audit Office observed that the dam's power output had been reduced by 40 per cent due to reduced water availability and that 3,900 more families than initially planned had had to be resettled, and that 80 per cent of those 30,000 resettled were still dependent on food subsidies up to four years after its completion. Their report concluded that 'the project had not generated the UK commercial return envisaged' (NAO 1992: 30), a conclusion set against recent recognition of the smaller scale cascade systems of the Dry Zone as a sustainable measure of watershed management (Bebermeier *et al.* 2017). In this case study, bigger is not necessarily better.

Disaster risk, resilience and the Classic Maya (*c.*250–900 CE)

Our third and final case study explores how Classic Maya urban–rural interaction (URI) in the southern lowlands of present-day Belize, northern Guatemala and southeast Mexico met the challenges of annual seasonality and periods of climate instability (Figure 12). Gone are the days when scholars and the public imagination envisioned ancient Maya theocratic ceremonial centres led by peaceful priest rulers, who looked more to the stars than to political engagement (Thompson 1966). More recently, the decipherment of Maya inscriptions and archaeological research aided by LiDAR mapping have revealed a tropical world with hundreds of cities, whose kings kept records of their successes in battles and other political machinations (Martin 2020). Cities, on average about 25 kilometres apart from each other, were surrounded by dispersed rural farmers who were drawn to cities for access to the massive artificial reservoirs during the five-month annual drought between February and late June. In fact, the entire Maya way of life has to be understood with regards to rainfall dependency, seasonality, and their reliance on water systems beginning about 400 BCE

(Scarborough 2003: 50–1; 2007). The Maya met these challenges relying on ingenuity, labour and stone tool technology since this area of the tropical world lacked beasts of burden, wheeled carts and metal tools.

The Maya lowlands is composed of limestone hills and ridges that are largely covered by deciduous hardwood forests and dispersed and variously sized pockets of fertile soils (Ford & Nigh 2015). Further, topography, including entrenched rivers, and dispersed resources discouraged large-scale irrigation systems. Annual rainfall ranged from 135 to 370 centimetres, 90 per cent of which falls during the seven-month rainy season from late June through January (Scarborough 1993). While seasonal swamps or wetlands, 40–60 per cent of any given area (Dunning *et al.* 2006), flourish during the rainy season and become desiccated during the dry season, elsewhere much of the rain percolates through the porous limestone bedrock. Small- and large-scale water containment and conservation systems were vital during the annual dry season and agricultural downtime, especially for drinking water. In the rainy season, farmers were dispersed in their fields during the agricultural intensive period. Consequently, there was a degree of seasonal mobility—and power. Dispersed farmers lived in self-organising or heterarchical communities during the rainy season and became enfolded or nested into urban hierarchical systems during the dry season (Scarborough & Lucero 2010).

The Global Climate Risk Index places Guatemala in the second highest tier, and Belize in its third highest (out of five; https://germanwatch.org/en/19777, accessed 13 June 2021). While not as high as Nepal (first tier), the risks are real in low-lying Central America, evidenced by climate refugees heading north to the US border. Global climate change and concomitant climate instability are a great risk to crops and water supply. In the past, the Maya dealt with extreme weather events, evidenced by long occupation histories—cities lasted over 1,000 years (*c.* 300 BCE–900 CE). This success stands in stark contrast to today. For example, the October 2010 Hurricane Richard swept through central Belize with a vengeance. Yalbac Ranch properties, where Lucero works, was ground zero. The differential impact on ancient versus modern urban infrastructure was notable. We found minimal damage at the Classic Maya medium-sized city of Yalbac, which the Maya had abandoned by 900 CE. In contrast, modern infrastructure required replacement or repair—roads, buildings, bridges, ferries, and so on. In another, more extreme case, the Belize government ended up building a new capital, Belmopan, from scratch in 1970 in central Belize after they tired of rebuilding parts of Belize City along the coast of the Caribbean Sea after particularly harsh hurricane seasons. It is telling that archaeologists do not find any Maya settlement in areas hardest hit today by hurricanes and tropical storms. In nearly every circumstance, Maya materials and methods are more suitable for the humid semi-tropics, for example, pole and thatch versus cinder blocks and metal roofing. Pole and thatch houses are dark, damp and relatively cool, as is Classic Maya

Figure 12. Map of the Maya area showing major cities. (Image: L.J. Lucero).

limestone monumental architecture. Maya traditional knowledge is astounding and relevant, but rarely considered in infrastructure and policy decisions.

Archaeologists have now recorded hundreds of Classic Maya cities, some that supported up to 80,000 people, if not more, and encompassed areas up to 200 square kilometres. Each had their own king supported by rural farmers (Lucero 2006).

Some kings had more power than others, especially those at Tikal and Naranjo in Guatemala, Calakmul in Mexico and Caracol in Belize, none of which are located near lakes or rivers. Their low-density, dispersed agrarian urban system integrated water and agricultural systems, cities, farmsteads and communities, exchange networks, and resources (Lucero *et al.* 2015). The organic expansion of the largest cities revolved around water capture and storage to replenish reservoirs, crops and people (Scarborough 1993; 2003; 2007). The massive gravity-based reservoir system became increasingly larger and more sophisticated, incorporating dams, channels, filtration and so on (Scarborough *et al.* 2012). For example, causeways (*sacbeob*) also functioned as dams and walkways (Figure 13). Maintaining reservoir water quality would have been crucial to curtail the presence of water-borne parasites and diseases, such as hepatic schistosomiasis, and the build-up of noxious elements such as nitrogen (Burton *et al.* 1979). The Maya kept water clean by creating wetland biospheres using certain surface and sub-surface plants. Clean water is indicated by the presence of *Nymphaea ampla*, a species of water lily that can only flourish in still, clean water—and it also symbolises Maya kingship (Lucero *et al.* 2011).

Rural farmers depended on urban reservoirs during the dry season. In addition, cities exerted a centripetal pull on rural Maya through markets, public ceremonies and other large-scale public events (Lucero 2006). In turn, urban-based royals depended on the rural populace to fund the political economy in the form of labour, services such as craft specialists, hunters; agricultural produce such as maize, beans, manioc, squash, pineapple, tobacco, tomatoes; and forest resources, such as wood, fuel, construction materials, medicinal plants, chert, game, and fruit. Maya farmers planted non-contiguous plots to prevent the spread of pests and used diverse, localised, small-scale extensive and intensive subsistence technologies that included 'terraces, dams, canals and raised fields that were used to grow the staples of maize, beans and squash in house gardens, short-fallow infields, long-fallow outfields and combinations of these techniques' (Lucero 2017: 166). In addition to farming, the Maya promoted certain economically and culturally significant flora and fauna (Gómez-Pompa *et al.* 1987). Forest management strategies also likely included culling, land clearing, intentional fires for hunting and gathering wood for fuel, resource extraction including clay and chert for pottery and tool production, as well as limestone and wood for building materials (Ford & Nigh 2015). The selective cultivation of species in orchards, home gardens, managed forests or tended fields in fallow allowed for cities and rural farmsteads to sustain themselves locally, sustainably (Fedick 2010; Ford & Clarke 2016; Lentz *et al.* 2015). Forest management, in addition to the use of diverse agricultural strategies, encouraged subsistence flexibility and long-term, sustainable investment in the landscape.

The Maya relied on rainfall to nourish their fields and replenish reservoirs. Consequently, a series of prolonged droughts that struck between *c.*800 and 930 CE

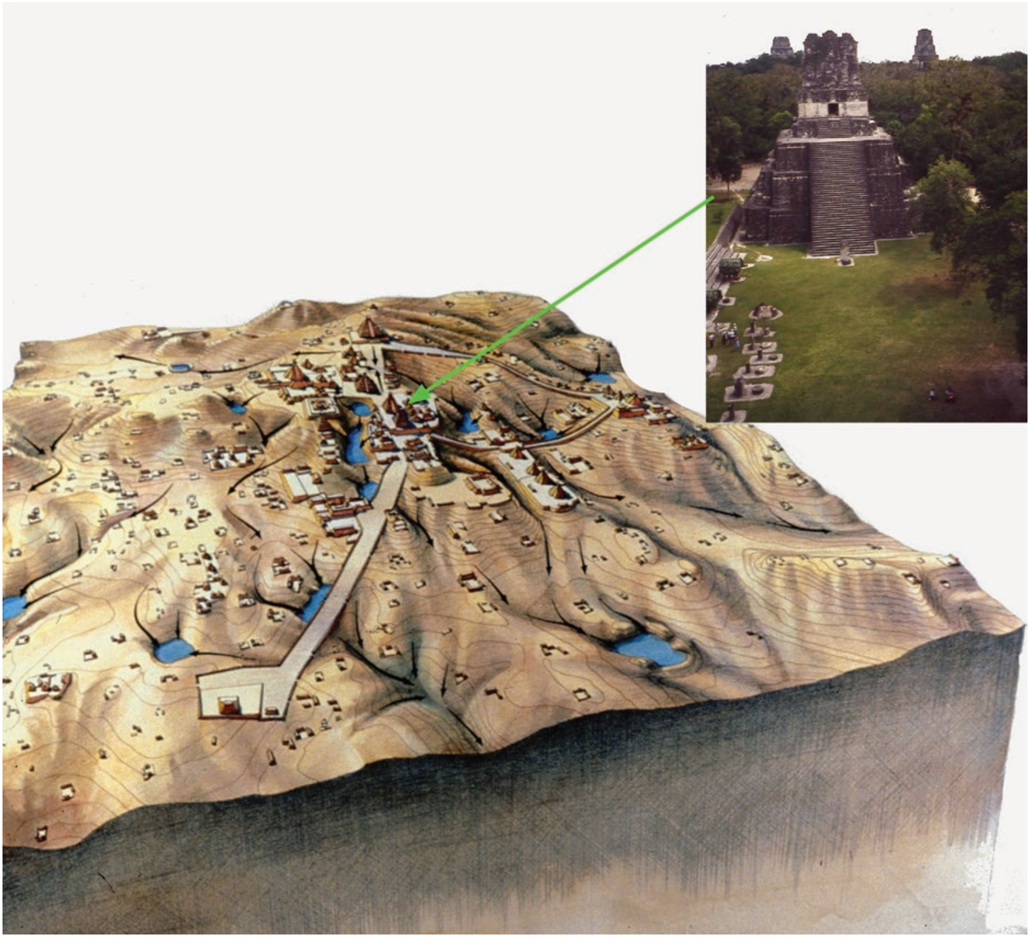

Figure 13. Rendition of Tikal, Guatemala, depicting causeways, reservoirs and open areas for gardens or even fields and orchards (Image: Vernon Scarborough) with view of Temple II (Image: L. J. Lucero).

(Douglas *et al.* 2015; Medina-Elizalde *et al.* 2010) had major repercussions (Lucero 2017). When reservoir levels dropped, water quality worsened and water lilies died, along with Maya kingship. Droughts led to crop failure and exacerbated any existing problems, including erosion, deforestation and overuse of resources. Kings had become dependent on the increasingly intricate, complex and interlinked water systems, setting the stage for their own downfall when the rains did not come, or came too late or too little (Lucero *et al.* 2015). The subsequent urban diaspora resulted in up to *c.*90 per cent (Turner & Sabloff 2012) of farmers leaving the interior southern lowlands for coastal areas, major rivers, or larger lakes, such as the Belize River and Lake Petén Itzá, where market towns and trade thrived (Graham 2011; Masson & Freidel 2012; Sabloff 2007). While this response was drastic, it was an adaptive strategy but one that worked as evidenced by the over seven million Maya currently living in Central America and beyond (McAnany & Gallareta Negrón 2009). Abandoned cities were never re-occupied, which unfortunately makes looting, destruction, such as fill from monumental buildings used as road fill, and building over all the more easier.

Even when Maya population peaked *c.* 600–800 CE in the Late Classic period, the Maya relied on diverse strategies to avoid depleting the resources upon which they relied—fertile soils, water, and diverse flora and fauna. In the past, the Maya URI supported more people than presently: current population density 'remains about one to two orders of magnitude less than the density' found in the Late Classic, indicating their long-term adaptation (Turner & Sabloff 2012: 13912). Further, LiDAR mapping in northern Guatemala reveals an anthropogenic landscape interspersed with forests, leading archaeologists to estimate a population of 7–11 million in the central Maya lowlands in the Late Classic (Canuto *et al.* 2018). The Maya landscape was a mosaic of settlement, subsistence features and managed forests that supported a farming lifestyle for 4,000 years without massive deforestation, a fact that goes against current practices of clear-cutting and mono-cropping.

Prospect

As is clear from the three case studies presented, archaeologists have the unique ability to review the process of environmental change and resilience from much deeper and richer timescales, and have learned detailed lessons about societal and technological adaptation from the past. Indeed, as we have stressed, one of the most powerful lessons from the past is that the key to societal success lies in a community's ability to recognise the need to adapt and adjust their social and economic scaling and integration to meet longer-term trends (Weiss 2016: 62). There is, however, an equally significant lesson that communities, particularly those agglomerated into states, need to be aware that even successful adaptations can lead to irreversible path dependencies. In this context, we use path dependencies to refer to processes of 'how people—and the institutions they create—become entangled (Hodder 2011) in situations from which they cannot easily extricate themselves … The situations may involve relationships and social institutions as well as material circumstances, and the entanglements develop over time' (Hegmon *et al.* 2016: 173).

The case study of climate change, disaster risk and resilience in Nepal demonstrated a history of successful technical adaptation in Nepal to threats from disasters, both flooding and tectonic. In the former, analysis of settlement location within the Terai, and the urban morphology of Tilaurakot-Kapilavastu, demonstrated that communities selected fossil alluvial ridges to avoid annual inundations (Verardi 2007) and that larger settlements were able to concentrate greater resources in flood defences in the form of moats and ramparts (Davis *et al.* 2016). These adaptations lowered the risk to their inhabitants but still provided them with proximity to water for cultivation and transport. Many modern settlements established off these ridges have almost annually suffered from the anguish of flooding.

Although only 300 kilometres northeast as the crow flies, the Valley of Kathmandu faces a very different challenge in the form of intermittent high magnitude earthquakes. Long the focus of art historians and architects, little was known about their foundations or technological innovations, with a fairly consistent belief that most were less than 500 years old. The deployment of a unique interdisciplinary research team of archaeologists, geoarchaeologists, architects, structural engineers, geotechnical engineers, heritage professionals, artisans and a Sanskritist demonstrated that one of Kathmandu's most iconic monuments, the Kasthamandap, had successfully withstood regular earthquakes for over a millennium. Field and laboratory analysis of samples from its foundations and superstructure have demonstrated a highly advanced indigenous technology with evidence ranging from the use of 'engineered' soils and mortars to avoid liquafraction to the use of copper sheet around timber members in conservation interventions to both act as a waterproofing but also as a chemical retardant for both mould and termites (Coningham *et al.* 2019). Of course, the deep irony is that the details of this highly advanced structure could only be fully understood after its collapse in the 2015 Gorkha Earthquake, a collapse accelerated by poor modern conservation interventions in the 1970s and 1960s.

The uniqueness of the story of the Kasthamandap reinforces the challenges of understanding why some historic structures collapsed in Kathmandu and others did not. Moreover, the typical contemporary domination of 'educated professionals', such as architects and engineers with internationally recognised qualifications, over highly experienced skilled artisans further accentuates this situation. This is played out in parallel with the preference of modern materials with internationally recognised standards, such as those benchmarked by the International Standards Organisation, over vernacular and indigenous materials—creating two separate worlds. The current gaps between the two are not being investigated, as donor agencies do not fund 'research' and research agencies are not frequently tempted to fund applied research, particularly with the recent cutting of GCRF funding in the UK. As a result, we do not actually know how many individuals were killed in the 2015 earthquake by vernacular buildings rather than those constructed in modern materials. Similarly, we do not know how many of those vernacular structures which did collapse had had modern materials assimilated, creating hybrids, which as our team engineers identified, mixed materials which perform in very different ways and mixed rigidity with flexibility ending often in disaster. The dangers of hybridisation are also found in the trans-Himalayan walled city of Lo Manthang, where increasing rainfall has been met by some residents with the deployment of plastic sheeting over their mud roofs. While keeping rain off the mud treatment, the plastic encourages the build up of moisture where the two join, leading to the rotting of the timber supports and the collapse of the ceilings and walls. Again, as in the case of Kathmandu, reference to traditional artisans offers a way of preserving these unique structures despite the environmental changes by referencing indigenous knowledge based on millennia of experimentation and adaptation.

Our second case study, disaster risk, adaptation and resilience in Medieval Sri Lanka, offered a very clear example of the development and employment of mega-infrastructure to lessen the risk of drought as the state at Anuradhapura developed and expanded. Its success is striking as it allowed an urban agglomeration of perhaps 200,000 people in the northern Dry Zone of the island. This significance is underpinned by the facts that the areas's natural carrying capacity is only 0.4 people per square kilometre and the modern city had a population of less than 70,000 in 2012 (Department of Census and Statistics 2012). While historians and archaeologists have tended to be overwhelmed by the integrated system of vast reservoirs and canals, the parallel rural system of simple gravity-fed cascade tanks have been less intensely studied—perhaps drawn to what Edmund Leach termed the 'propaganda myth' of kingship and its associated mega-works (1959: 15). Similarly, scholars have been drawn to the architecture of the monastic complexes which surrounded the city, rather than the network of rural communities which generated the surplus which supported them. This diversity of systems appears to have allowed farming communities to have survived the collapse of the mega-infrastructure as climatic instability, combined with societal adjustments with access to labour, forced a path dependency which could only conclude with an almost entire 'systems collapse'. In this case, the parallelism allowed the farming communities to relocate to more favourable environments, both in terms of climate and social contexts. The continued favouring of mega-infrastructure by both donors and governments risks the creation of similar pathway dependency, where the interdependencies are so entangled that adaptation becomes irreversible and bigger is certainly not better.

Clearly, parallel lessons also come from our final case study, disaster risk, resilience and the Classic Maya. The tracing of urban–rural interaction and adaptation to the seasonal availability of water in another part of the tropics, traced echoes of Sri Lanka's 'Hydraulic Civilization' with a landscape of dispersed farmers. Indeed, recent research with LiDAR has demonstrated that the Maya landscape was a mosaic of settlement, subsistence features and managed forests that supported a farming lifestyle for 4,000 years without massive deforestation, a fact that goes against current practices of clear-cutting and mono-cropping. Self-organised, or heterarchical, during the rainy season, they were enfolded or nested into urban hierarchical systems during the dry season (Scarborough & Lucero 2010). Their choice of localities, evidenced by deep occupation histories, demonstrated the awareness of disaster risk and its mitigation; a lesson only too clear when compared with the widespread devastation caused amongst new settlements during extreme weather, such as Hurricane Richard in 2010. The outcome of centuries of experimentation, Maya vernacular architecture demonstrates successful adaptation to its environment in stark contrast to the increasingly ubiquitously favoured cinder block and metal sheet roofing. As noted above, Maya traditional knowledge is astounding and relevant, but rarely considered in infrastructure and policy decisions. Their indigenous knowledge of both water and forest management underpinned the development of state level societies, despite the lack of metal, beasts of burden and wheeled carts. However, the massive urban gravity-based reservoir systems which supported those cities became increasingly larger and more sophisticated, incorporating dams, channels and filtration (Scarborough *et al.* 2012). These path-dependent practices were successful adaptations during a relatively stable climate but were unable to mitigate the series of prolonged droughts that struck between *c.*800 and 930 CE (Douglas *et al.* 2015; Medina-Elizalde *et al.* 2010). Crop failure, erosion, deforestation and the over-investment of dwindling resources in increasingly intricate, complex and interlinked water systems resulted in the dispersal of urban communities (Lucero *et al.* 2015), and a process which Yoffee refers to as 'ruralisation' (2005: 60).

Archaeologists generate evidence to identify lessons from the past. However, they can, and should also, be proactive in disseminating their relevant research beyond academic publications to engage with people, communities and policy makers. To take a step in this direction, the American Anthropological Association created the Climate Change Task Force (2010–2014) to address the role of anthropology in dealing with climate change from a human perspective rather than a political and economic top-down one—adaptation, resilience and vulnerability. The task force, on which Lucero served, included archaeologists, cultural anthropologists and biological anthropologists. We met several times between 2012 and 2014 at conferences and seminars, supported by the School for Advanced Research (Santa Fe, New Mexico), the Atlantic Philanthropies (New York City) and the American Anthropological Association. The resulting report, available for free online (see Fiske *et al.* 2015), lays out step by step not only the usual topics when discussing the impacts of climate change, such as the causes of CO_2 emissions and mitigation, but those taken at the community level. We also generated a Statement on Humanity and Climate Change that lists the eight key intersections of climate change and anthropology—including one devoted to archaeology (see also Cox 2014; Turner *et al.* 2016):

> *The archaeological record reveals diverse human adaptations and innovations to climate stresses occurring over millennia, providing evidence that is relevant to contemporary human experience. The archaeological record shows that diversity and flexibility increase resilience to stress in complex adaptive systems, and that successful adaptations incorporate principles of sustainability.*

Future disasters are a given, especially in view of global climate change. Risks can be mitigated if we look to our past for lessons, because it embodies practices, challenges, strategies, successes and failures from which to devise sustainable solutions (Fiske *et al.* 2015; Isendahl *et al.* 2018; Lucero & Gonzalez Cruz 2020). For example, in an article comparing ancient Anuradhapura, Angkor, and Tikal (with Roland Fletcher), we concluded with this lesson, that: 'In the end, the different histories of kings and farmers relate to the different constructs in which they existed: inflexible *vs* flexible strategies; a reliance on massive *vs* small-scale diverse water systems; and entrenched and rigid *vs* resilient and adaptable systems' (Lucero *et al.* 2015: 1151). Thus, it is not only vital to save our cultural heritage and that of others for the sake of history and tourism, but for lessons from which we can all benefit. While we have discussed here three semi-tropical societies, the points we make are relevant for all tropical regions—and future urban planning globally. We have presented cases of successful and unsuccessful adaptations in urban settings from the tropical past to provide instances of how archaeology and archaeologists can also play a greater role in future urban planning.

Having shed doubt on the success of some mega-infrastructure irrigation projects in the tropics, we also need to acknowledge that there are dangers associated with the development of modern urban mega-infrastructure on historic urban infrastructure. This is exemplified by Lahore's Orange Line, part of the China Pakistan Economic Corridor initiative, whose 27.12 kilometre line was built at a cost of US$1626 million (CPEC 2021). Its path along the line of the historic Grand Trunk Road, however, impacted 12 protected Medieval and Colonial monuments and buildings, including within 28 metres of the 17th century Mughal Shalimar Gardens UNESCO World Heritage Site (Coningham & Lewer 2019: 154) (Figure 14). We could write a book on similar examples of our past being erased globally, and with it knowledge of sustainable urban planning and indigenous practice and knowledge.

To conclude, as we noted earlier, the ancient Indian scripture Yajurveda states the importance of taking care of Mother Earth so that she can take care of us. Future discussions of urban infrastructure must keep this in mind, so we, too, can live in cities for millennia. Combining knowledge acquired by interdisciplinary teams from the archaeological record with indigenous knowledge are powerful tools for future sustainable urban planning. Our case studies leave little doubt of this fact. In brief, the purpose of this work is to illustrate that to save ourselves (and Earth), we must also save our past.

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Figure 14. View of the Orange Line's viaduct foundation beside the Chauburji Gateway in Lahore, Pakistan. (Image: Durham UNESCO Chair).

University of Bradford, and other partners. The British Academy's Global Challenges Research Fund's Project 'Reducing Disaster Risk to Life and Livelihoods by Evaluating the Seismic Safety of Kathmandu's Historic Urban Infrastructure' (CI170241) sponsored the fieldwork, as well as the co-design and installation of the Dhukuti museum display with additional financial support from UNESCO (Kathmandu), the Alliance de Protection du Patrimoine Culturel Asiatique, the Pashupati Area Development Trust and Durham University's Institute of Medieval and Early Modern Studies (IMEMS), now hosted by the Hanuman Dhoka Museum Development Committee (Department of Archaeology, Government of Nepal). We are very grateful to the Austrian Academy of Sciences for their partnership and Vienna-based symposium, and to the National Museum in Kathmandu for hosting our final dissemination workshop. Finally, we would like to acknowledge the support and passion shown by Mr Rajesh Shakya and the other members of the Kasthamandap Reconstruction Committee, the master craftsmen and the ward members who are rebuilding the Kasathamandap. We also acknowledge the contributions of the following colleagues to our broader discussions: Roland Fletcher, Kosh Prasad Acharya, Ian Simpson, Kai Weise, Prishanta Gunawardhana, Shahnaj Husne Jahan, K. Krishnan, Mark Manuel, Christopher Davis and Keir Strickland.

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The Principal Investigator, Robin Coningham, holds UNESCO's 2014 Chair in Archaeological Ethics and Practice in Cultural Heritage at Durham University, and is committed to the protection of cultural heritage, joining over 30 international missions for UNESCO. He has co-directed UNESCO's archaeological fieldwork within the Greater Lumbini Area of Nepal since 2011 and was invited to co-direct post-disaster excavations in Kathmandu with Kosh Prasad Acharya and Ram Bahadur Kunwar after the 2015 Gorkha Earthquake by UNESCO and the Government of Nepal. His publications include the 2012 *Appropriating the Past: Philosophical Perspectives on the Practice of Archaeology* and the 2015 *Archaeology of South Asia* with Cambridge University Press, and Pivot Palgrave's *Archaeology, Heritage Protection and Community Engagement in South Asia* in 2019.

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The current status of Migrant Disaster Victim Identification in the Canary Islands

Caroline Wilkinson and Maria Castaneyra-Ruiz

Abstract: This migrant disaster victim identification report is based on an 18-month British Academy funded project, which focused on the Canary Islands, clarifying the state of play of documentation and connections with West Africa: primarily with Senegal, which is described as the main origin of the migrants to the Canary Islands. With the collaboration of Italian and Spanish academics and the utilisation of Canarian data, the report interrogates the challenges associated with the identification of migrant victims off the coast of the Canary Islands through fostered networks in the Canary Islands and Senegal. Finally, the report presents craniofacial depiction/analysis as an alternative biological and biometric tool for Migrant Disaster Victim Identification (MDVI). This project did not involve the implementation of migrant identification and this will hopefully be achieved through follow-up projects. The report ends with a summary of the current status and provides recommendations for future MDVI.

Keywords: migrant, disaster, victim, identification, Canary Islands, Senegal.

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The United Nations High Commissioner for Refugees (UNHCR) estimates that as many as 20,000 migrants have died making Mediterranean crossings in the last decade, and few migrants who perish at sea are ever positively identified. This represents a global humanitarian crisis.

Illegal immigration is currently a reality in many nations (Brian & Laczko 2016) and economic migration is a critical issue for many European countries. Where migrants travel great distances, a large percentage reach the end of their lives attempting to cross bodies of water and inhospitable landmasses between origin and destination. Sometimes their bodies are found, but unfortunately, many are lost at sea, in deserts or in wasteland. Each unidentified migrant death leaves a family destined to uncertainty with potential administrative, legal and social repercussions, and the International Organization for Migration (IOM) states that in 2016, over 380,000 irregular migrants tried to enter Europe and more than 5,000 of these are missing or have died.[1] Between 1 January and 17 February 2020 alone, 291 migrant deaths were recorded by IOM, national authorities and media sources.

However, although Europe woke up to the challenges of migrant deaths in 2013, it was 17 years earlier when the first boat arrived with irregular migrants to the Canary Islands. This pathway was one of the most utilised routes for the African migrants to reach Europe (Guillén 2011) and the most active years were 2000–6, when boats with greater capacity arrived and the migrant demographics diversified. More than 30,000 men, women and children arrived in the Canary Islands in 2006, with around 6,000 recorded deaths (Kemp 2016) and with many more suspected deaths. In one fishing village in Senegal with 40,000 inhabitants, it is said that everyone has lost someone, with as many as 1,500 young men who died/disappeared en route to Spain in 2006 (Andersson 2014). At the onset of this Canarian phenomenon, there was no process for how to deal with the migrant dead, and this new problem overwhelmed the islands. Some of these bodies were recorded (Last *et al.* 2016), but many migrants were buried without any information available for identification. Boats of migrants have continued to arrive ever since (23 boats carrying 708 migrants arrived in January 2020)[2] and this has resulted in the creation of new institutions,[3] laws[4] and border rules[5] relating to the treatment of immigrants.

Current Disaster Victim Identification (DVI) databases (e.g. Interpol system) may not include the most appropriate information for migrant DVI (MDVI), as many of the usual methods of identification (DNA; fingerprints; dental) are often not available

1 https://missingmigrants.iom.int/

2 www.interior.gob.es/

3 Casa Africa, www.casafrica.es/; OBITen, www.obiten.net/

4 Plan Canario Inmigración 2002–2004; BOPC 2011.

5 ORDEN PRE/3108/2006.

Figure 1. Map of illegal migrant routes from Africa to the Canary Islands.

due to the socioeconomic conditions of the countries of origin along with water damage and/or rapid decomposition. Delayed access to the migrant bodies may further confound these comparative methods. However, the contemporary rise of global networks and the use of mobile phone images has led to public acceptance of social media use in the search for missing people, and platforms, such as Facebook and Instagram, are frequently utilised to 'post' ante-mortem images of missing people (Laztza Nadeau 2017). This has created an opportunity for digital craniofacial analysis to be employed to match ante-mortem images to post-mortem images or depictions. Some European forensic databases have utilised 3D imaging for craniofacial analysis (Cattaneo *et al.* 2010; Brough *et al.* 2012), but these tend to be limited to national forensic casework rather than large-scale disaster scenarios. The 2018 IOM report states that the majority of deceased migrants are identified visually by family members and there are significant problems associated with visual recognition of the dead due to psychological/social pressures and post-mortem changes (Wilkinson & Tillotson 2012). Craniofacial analysis is a valuable tool for forensic investigation and many individuals have been successfully identified as a direct result of a publicity campaign (Wilkinson 2010), but this technique has never been utilised in MDVI.

Table 1. Migrant Disaster Victim Identification (MDVI) organisations in the Canary Islands.

Organisation in Canary Islands	*MDVI process*
Institutes of Medicolegal & Forensic Science (IMLCF)	Autopsies and reports pass to the Guardia Civil Bodies sent to the cemeteries Information applied by the Tribunal Superior de justiciar The judge is responsible for the official identification—report with body register number and burial site National DNA database for missing person (not criminal purposes). It is a blind database that cannot be consulted. It works just to search for matching Charitable bodies take responsibility for the burials
Consulate of Senegal	Store approx. 300 post-mortem photographs for migrants arrived at Tenerife/Gran Canaria Burials known—no more information Thought to be Senegalese
International Committee Red Cross (ICRC)	Update border death database (1994 until 2013) ICRC data it is the most adapted for the identification of migrants
Centre International pour L'identification de Migrants Disparus (CIPIMD)	Network of collaborators in Spain, Morocco, France, United Kingdom, Belgium, Switzerland Assist families to reclaim the bodies and identify through photography
Federation of African Associations in the Canary Islands (FAA)	Assist migrants who arrive to the islands Assist people who reclaim a family member to raise money to repatriate the body

Methodology

This 18-month research project was funded by the British Academy and focused on the Canary Islands, clarifying the state of play of deceased migrant documentation and missing persons' connections with West Africa: primarily with Senegal, which is described as the main origin of migrants to the Canary Islands. This report is not commissioned nor politically aligned. Craniofacial anthropology researchers from Face Lab at the Liverpool John Moores University collaborated with identification experts from the Laboratory of Forensic Anthropology and Odontology (LABANOF) at the University of Milan and the Faculty of Medicine at the University La Laguna, Tenerife. The authors and collaborators are practising forensic anthropologists/academics with no formal links to any of the relevant identification groups, and the research focused on the Canary Islands, as one of the most popular routes from West African to Europe, with large numbers of unidentified migrant victims buried across the islands.

Table 2. Numbers of migrant burials on the island of Fuerteventura by municipality and source as compared to the published data.

Fuerteventura migrant burials			
Municipalities	www.borderdeaths.org	Niches counted	Difference
La Oliva	9	8	-1
Puerto del Rosario	3	6	+3
Antigua	32	37	+5
Tuineje	60	23	-37
Pajara	22	14	-9
Total	**126**	**88**	**-38**

Data, narratives and information were collected through fostered networks in the Canary Islands (see tables 1 and 2) and Senegal (see table 3), during a nine-month research period in the Canary Islands and a one-month research visit to Senegal. In the Canary Islands, a review of the existing migrant data was performed using forensic anthropology records and information from sources such as the Guardia Civil, Red Cross, newspapers and courts archives (see table 2). In Senegal, the status of current West African missing people records was assessed through meetings/interviews with lay and community groups, identification agencies, police officers and government agencies and knowledge exchange sessions with key contacts. Finally, the information gathered from the Canary Islands and Senegal was assessed by all partners, in order to co-design practical standards for future international MDVI storage resources and MDVI policy (see table 4). A planned MDVI 2020 symposium in Liverpool with invited international experts was postponed due to the COVID-19 pandemic.

This resulting research report therefore interrogates the challenges associated with the identification of migrant victims in the Canary Islands, and evaluates the opportunities afforded by the worldwide use of social media and mobile phones to present craniofacial depiction/analysis as an alternative biological and biometric tool for MDVI. This project did not involve the implementation of migrant identification and this will hopefully be achieved through follow-up projects. The report ends with a summary of the current status and provides recommendations for future MDVI.

Current practice

The IOM and many identification experts are deeply troubled by the stark difference between the extensive efforts by European countries/organisations to systematically, efficiently and effectively identify victims of armed conflict or a humanitarian/

Table 3. Identification organisations based in Senegal with missing migrant data.

Organisation	*About*	*Missing migrant information*
Réseau Migration et le Développement (REMIDEV)	2007 government-supported network to bring together NGOs and Senegalese associations involved in migration Concerned with the freedom of movement and migrant rights	Connection with IOM Dakar, but do not collaborate as do not share repatriation policies Senegalese government collaborates with activities of national migration and immigrants in Senegal, but not clandestine migrants or missing migrants or their families
Collective of Victims' Families of Clandestine Emigration (COFLEC)	Created after the death of the founder's son in a canoe heading to the Canary Islands in 2006 Supported by number of Spanish NGOs	ACRFAT (Clandestine Returned and Affected Families of Thiaroye Sur-mer) are associations from the same district in Dakar—recorded 374 deaths and 240 cases of people disappeared between 2006 and 2009
Diaspora Development Education Migration Senegal (DIADEM Senegal)	Not-for-profit organisation to improve living conditions and promote dialogues between different stakeholders, in relation to migration, mobilities, education and development challenges	Data collected from 1,000 families in 35 regions of Senegal with lost migrant relatives to Canary Islands Importance of involvement with local religion and culture to promote the benefits to Senegalese communities Emphasise the issues of the data protection law Request death certificate to help children's education and family's heritage
Laboratory of Studies and Research on Gender, Environment, Religion & Migration (GERM)	GERM & Faits de Sociétés is a research group from Gaston Berger University in Saint-Louis, Senegal. It is made up of research professors, academics or researchers affiliated with national and international institutions	The government does not take responsibility for clandestine migration and victims—this is a taboo subject There are associations linked with migration in all districts of Dakar, but there is not an officially recognised list Family liaison considered critical
Puente Humano	2004 project that made connections with students from Canary Islands and Senegal to raise awareness so that Senegalese youth do not consider clandestine migration	At this moment, the population does not trust NGOs or international cooperation Louga is a migration village, many of the houses and business have been created with money from migrants
Hahatay Gandiol	Raises awareness of the dangers of clandestine migration	2006 personal experience of trip from Dakar to La Gomera in a canoe (lasting eight days)

Table 3. Continued

Organisation	*About*	*Missing migrant information*
ICRC Senegal	International Committee Red Cross in Senegal	Created the project 'Trace the Faces' where the families can try to find their missing migrants Do not collect data relating to physical appearance In Senegal, created a project for psychological support for families with missing migrants who are suffering financial, legal or administrative difficulties Creating national list of missing persons
The International Organization for Migration (IOM)	Missing Migrants Project (MMP)	Online MMP—includes realistic database of missing migrants from Senegal More interested in the live movement of people between Canary Islands and Senegal than the identification of migrant victims

natural disaster, and how little effort is made to identify migrant disaster victims (Latza Nadeau 2017; Singleton *et al.* 2017). There appears to be a second-class system for processing migrant deaths. The IOM states that migrants' rights should be protected during the whole circle of migration (IOM 2013), and this is especially challenging where the individuals originate from low-income countries, where identification details are absent and migration is undocumented or unmonitored. The social, legal and religious implications of misidentification are manifest and the need to identify the dead and its importance for humanitarian, administrative, judicial and other purposes are universal values enshrined by domestic and international law, including the four Geneva Conventions of 1949 and their Additional Protocols of 1977. Some European countries have created a database to collect DNA and anthropological information prior to internment of migrant victims in order to facilitate future identification (Cattaneo *et al.* 2010; 2015). However, many other countries do not even try to collect information on the migrant dead and bodies are cremated or interred without any identification process. There is no central international database that connects the images, numbers and internment locations, and certainly no collection and cataloguing of biological profiles or identifying characteristics. The European Commissioner for Human Rights (2007) argued that it was imperative to begin a process to identify and account for the thousands of 'missing' undocumented migrants whose identities are unknown. However, despite the frequency and magnitude of these tragedies over

Table 4. Recommended content for an online MDVI database.

Post-mortem	*Factor*	*Details*	*Data*	*Storage format*	*Application to MDVI in the Canary Islands*
Migrant Disaster Victim	Case	Body retrieval report	ID number Date Island municipality	Coastguard/police report Interpol DVI form (pink)	Possible from records or news reports + burial location
	Disaster	Type of disaster	Number of casualties Origin of migrants Condition of bodies	Coastguard/police report Interpol DVI form (pink) Scene photographs	Possible from records or news reports
	Biological profile	Sex Gender Age Population Height BMI	Descriptions Measurements	Pathology or anthropology report Interpol DVI form (pink)	Osteology report possible from skeleton
	Clothing Belongings	Type Colour Size Features Damage	Descriptions Photographs	Coastguard/police report Interpol DVI form (pink) Image gallery Exhibits	No
	Physical indicators	Tattoos Moles/marks Scars Implants Modifications Medical Hair Skin Eyes Trauma Prostheses	Descriptions Photographs CT scans Laser scans	Interpol DVI form (pink) Image gallery File and image gallery File and image gallery Pathology or anthropology report	No osteology report possible from skeleton
	Facial indicators	Feature appearance Hair Eyes Scars Moles/marks Modifications Dental	Descriptions Photographs CT scans Laser scans	Interpol DVI form (pink) Image gallery File and image gallery File and image gallery Craniofacial report	Possible photos Possible craniofacial analysis from skeleton
	Biological indicators	DNA Fingerprints Odontology/ dental	Samples Set of prints Records and radiographs	Interpol DVI form (pink) Image gallery File Odontology report	Possible DNA Possible odontology report from skeleton

Table 4. Continued

Ante-mortem	*Factor*	*Details*	*Data collection*	*Storage format*	*Missing migrants*
Migrant	Identity	Name	ID documents	File Image gallery	Family
	Migration	Date Boat Passengers Route Organisation	Descriptions	Text Map	Family
	Biological profile	Sex Gender presentation Age Population	Descriptions Photographs	Interpol DVI form (yellow) Image gallery	Family
	Clothing Belongings	Identifying features	Descriptions Photographs	Interpol DVI form (yellow) Image gallery	Family Social media
	Physical indicators	Identifying features Medical Dental	Descriptions Clinical imaging Records Photographs	Interpol DVI form (yellow) Image gallery File	Family GP Dentist Social media
	Facial indicators	Identifying features	Descriptions Photographs	Interpol DVI form (yellow) Image gallery File	Family Social media
	Biological samples	DNA Fingerprints	Migrant belongings Family members		Family
	Mobile phone	Social media	Archival material	Text Links	Family

the last ten years, European governments have been slow to recognise that families have a right to know the fate of missing migrant relatives (Ben Attia 2016). It is worth noting that communication with relatives of the missing may create danger for the family and family members may be reluctant to speak to the authorities due to fears of criminal investigation, extensive funerary costs or social exclusion. Only 22 per cent of deceased migrants are ever identified (IOM 2018).

The International Organization for Migration (IOM) Missing Migrants Project is widely acknowledged as the leading authority on border deaths (Ampuero Villagran 2018; Cuttitta 2020) and included the first systematic compilation of data on 'migrants who have died or gone missing at the external borders of states, or in the process of migration towards an international destination' (Batalova 2018). The MMP collects information of the migrants' age, gender, origin, location, and cause of death, primarily sourced from IOM and government reporting along with NGO and media accounts, in order to create a globally accessible database. However, there are recognised, inherent difficulties to maritime migrant disaster victim identification, and these include:

1. Difficulty in determination of migrant origin—many do not carry identity documents/passports, or these may be lost/destroyed during the disaster (Ampuero Villagran 2018).
2. Migrant deaths may be actively covered up or left unreported if smugglers or traffickers are involved (Triandafyllidou and McAuliffe 2018).
3. Water-based decomposition, tidal movement and/or animal activity can lead to loss of clothing/belongings, physical features and facial appearance (Ellingham 2017).

Experts (Kovras & Robins 2016) state that identification is also hindered by the current lack of European nation legal provisions and international agreements resulting in ad hoc practices with poor funding, overlapping mandates, and unsystematic collection and storage of information. The 2018 Mediterranean Migrant Policy Report (05/02) by the United Nations University Institute on Globalisation, Culture and Mobility (UCUI-GCM) states that the management of dead migrant bodies is often categorised into five stages that include retrieval, transportation, autopsy, storage and burial/repatriation; with identification information collected, collated and evaluated at each stage (Ben Attia *et al.* 2017). As stated in the UNUI-GCM report (Ampuero Villagran 2018), the initial procedure at Mediterraean migrant disasters includes photographic recording of the body (taken by coast guards, police officers or forensic experts) and the attachment of a MDVI code that includes migrant gender and date of retrieval. Although coroners will usually examine the bodies and collect primary characteristics to report to the national authorities, full post-mortem examinations will only be requested if there are concerns related to the cause of death. Finally, the migrant disaster victims are transported to be buried in anonymous local graves; in the Canary Islands these are above-ground, sealed spaces/drawers in a wall to hold human remains, known as niches/crypts. Since identification is essentially the reconciliation of post-mortem (PM) data from the unknown body with corresponding ante-mortem (AM) data from registries or families of the missing, the practices currently in place for the management and identification of migrant bodies in the Mediterranean are largely inadequate (GMDAC 2016). In the aftermath of a disaster, critical evidence that migrants carry with them, including mobile phones, are often neglected. Much of the useful identification data stored on mobile phones can be accessed in social media or iCloud storage, but this data is never collected as it would involve interviews with families in the country of origin.

The Canary Islands

The Canary Islands are seven islands belonging to Spain located in the Atlantic Ocean close to the North African coast; the closest island (Fuerteventura) is 100 km from the port of Tarfaya in Morocco (see figure 1). These islands provide an illegal entrance into Europe from Africa through a maritime migration route that became popular from 1995 due to a particular set of political and geographic circumstances. Firstly, Spain joined the European Union in 1986, whereupon the Spanish cities of Ceuta and Melilla, that sit on the northern shores of Morocco's Mediterranean coast, became the European Union's only land entry points from Africa and their borders came under pressure from African migrants seeking a better life in Europe (see figure 1). Both port cities developed as military and trade centres linking Africa to Europe and have had limited self-government as autonomous communities since 1995. Enhanced security (perimeter fences, infrared cameras) was installed at their borders in 1995, due to pressure from EU member countries, forcing African migrants to consider alternative routes into Europe. Fall (2007) claims that illegal migration from sub-Saharan Africa to Europe and more specifically to the Canary Islands is probably linked to the enforcement of the border controls in the Spanish enclaves and transition countries (Mbaye 2014: Maher 2015). Secondly, after 2000, the border controls at the Straits of Gibraltar were intensified and this also forced illegal migrants to use boats to reach European coasts such as Lampedusa, Sicily or the Canary Islands (Adepoju 2008; De Haas 2006).

The first arrivals to the Canary Islands came via Morocco on small boats in the early years of the 1990s. These 'pateras' came mostly to the eastern islands and their success established the direct migration route (Rodríguez Díaz & Montes 2008). This route was used almost daily until the later years of the 1990s, when international agreements managed some control. The migrant origin then relocated to the more southern West African countries, making the routes longer and more dangerous. Many of these people were originally from Senegal, and the motto of thousands of Senegalese who tried to migrate illegally was 'Barsa wala Barsakh', which in Wolof means 'Barcelona or Die'. The small boats used also transitioned to the traditional Senegalese fishing canoes (cayucos), which had greater capacity accommodating more than 100 people. To understand the scope of this phenomenon, half of the 30,000 illegal migrants who arrived in the Canary Islands in 2006 (the peak) were Senegalese (Dudek & Pestano 2019), while 1,000 out of 7,000 African illegal migrants who died during the crossings in the same year were Senegalese.[6]

It has not been a priority for the Spanish or Canarian authorities to identify deceased migrants. For this reason, there is a paucity of data and no specific protocols

[6] Asociación Pro Derechos Humanos de Andalucía (2007) http://www.apdha.org

for migrant identification. This status was denounced in a 2018 human rights report,[7] that stated:

> *[I]t should be noted that there is no government agency dedicated to the identification of the corpses of people who have died on the boat while making the migratory journey, which represents a serious violation of rights, since, beyond the difficulties inherent in identification, the administration does not develop adequate mechanisms to carry it out.*

When a deceased migrant reaches the Canary Islands, the Civil Guard must take fingerprints and photographs, and depending on where the body is found, whether it is sea or land, the Civil Guard or the Police take responsibility. The bodies are taken to the institutes of legal medicine and a judicial case is opened. All the information generated feeds a national blind database for unidentified cadavers that is managed by the Security State Secretariat pending from the Ministry of Interior. The investigating judge and the forensic doctor investigate the cause of death and identification. In the Canary Islands, there are two Legal Medicine Institutes, one in each of the Canary provinces, located in Tenerife and Gran Canaria, while in the rest of the islands there are dependencies for legal medicine. The Tenerife Institute[8] was founded in 2002, and the registry of files has been standardised since 2009. The Legal Medicine Institute in Gran Canaria[9] was created in 2007 and since then records show 28 DNA samples from unidentified people, of which 22 are from buried migrants.

In the Canary Islands, the International Committee of the Red Cross (ICRC) is one of the few active groups attempting to identify the interred deceased migrants. We had the opportunity to meet with the Transregional Forensic Coordinator Euroasia, Jose Pablo Baraybar, who is the person responsible for ICRC in West African and the Canary Islands, and with Benedicte L'Eplattenier, Transregional Adviser for Restoring Family Links and Missing Persons in relation to migration. The Deaths at the Borders of Southern Europe Database[10] is the first collection of official, state-produced evidence on deceased migrants attempting to reach southern EU countries from the Balkans, the Middle East, and North and West Africa, and whose bodies were found in or brought to Europe. One of the biggest challenges in the personal identification of migrants is establishing their country of origin. The ICRC focuses on contextual events to track the possible provenance, using algorithms to predict the origin, based on the boat wreck information, survivors, and data from other countries (such as Italy). Jose Pablo and Benedicte explained that ICRC is currently updating the Deaths at the Borders of Southern Europe Database to 2019. This data is the most reliable source for Canary Islands data, recording 302 migrants buried in the Canary

7 http://ddhhfronterasur.org/assets/frontera-sur.pdf

8 The meeting was with the Director Jesus Vega of Instituto de Medicina Legal de Santa Cruz.

9 The meeting was with the Director Eva Bajo Tobio of Instituto de Medicina Legal de Las Palmas.

10 www.borderdeaths.org/

Islands, of which 249 are unidentified. One of the challenges in identification is the match between the AM and PM data; in Europe the PM database is extensive, but in West African countries the data may not exist, and it is therefore not possible to confirm identity.

In an attempt to update and clarify the numbers and associated details of buried migrants in the Canary Islands, we made a formal request to the Interior Ministry, applying for the number of cases and type of information (but not individual data). The same information was also requested from the Canarian Government to access the information that exists in the Legal Medicine Institutes. No responses have been obtained, although both directors expressed their willingness to collaborate.

In Fuerteventura, we made a formal request, through Judge Dean, to access information on the MDVI cases. The judge informed us that the request must be made through the government (we have made an application, which to date has had no response). As there was no response from the courts, we decided to apply to the island's municipalities who administer the cemeteries. There are six municipalities on the island (Fuerteventura), of which four responded, with three providing data: six burials from a single boat in 1999, one burial from 2003, and one niche with 13 bodies from 2003 and 2004. For municipalities that did not answer or provide data, we counted the visible niches in the cemeteries marked as migrant burials; 68 niches were counted. This made a minimum total of 89 unidentified migrants in Fuerteventura (see table 2). The Deaths at the Borders database recorded 145 migrants, of which 126 are unidentified (82 men, 2 women, 46 sex unknown). These figures suggest that some burial niches may contain more than one deceased migrant and some deceased migrants are not recorded.

Senegal

Senegal is a country located in West Africa, surrounding The Gambia and bordered by Mauritania to the north, Mali to the east, Guinea to the southeast and Guinea-Bissau to the southwest. After Senegalese independence from France in 1960, migration continued, and new destinations emerged across the world. The main motivations for migration are poverty and the lack of a future for young people (more than half of the Senagalese population is under the age of 20). Migration is synonymous with prosperity and families with migrant relatives have money, they can build houses, create new businesses and provide stability to the family economy. In contrast, families with relatives who do not make it to a migrant destination leave a large hole in the family economy. The typical Senegalese migrant is a 19–30-year-old man, although in the last decade young women have also become migrants, as a means of independence and power (Ndione *et al.* 2018).

It is not difficult to understand the thousands of Senegalese who embark for Europe via the Canary Islands. The peak of migration from Senegal to the Canary Islands was 2006, with more than 30,000 people arriving and more than 6,000 deaths in that year alone. After this peak, the wave of canoe arrivals declined due to new policies created by the governments of Spain, Morocco and Senegal, but although it seemed that this route had been abandoned, it has resurfaced as a popular route in recent years. In April 2020, 1,477 people arrived on the Canary Islands in 51 boats (Inmigracion Irregular 2020).

Senegal has adopted a new 'Plan for an Emerging Senegal in 2035' (PES) that forms the reference framework for the national economic and social policy over the mid- and long-term. To this end, the government has initiated actions designed to sustainably raise growth potential, as well as drive creativity and private initiative to satisfy people's aspiration for a better life. The government's three priorities are structural transformation of the economy, promotion of human capital and good governance. The Senegalese government does not currently have a migration policy and although there is government data relating to legal mobilisations inside and outside the African continent, there is no data relating to clandestine migrations.

Over the course of this project, we tried to arrange meetings and interviews with the government and the competent authorities; in some cases, they diverted us to different authorities and in other cases, never responded. In some of the interviews with researchers and associations, it was confirmed that the government is not interested in the identification of dead migrants. Laurent de Boeck, IOM deputy regional representative (The New Humanitarian 2006), stated 'There is little incentive to stop migration because it brings in more funds than development aid', and Ndione *et al.* (2018) stated 'There is no process of coordination of political relations between the migration and the national level of Senegal'. Since the Senegalese government has had a minimal interest in migration matters, there is no intention to account for the many people who have disappeared en route to Europe, let alone attempt to identify those migrants unlucky enough to be buried in Europe. This task and that of caring for family members has fallen to NGOs and organisations created by the local communities.

In Senegal, through the associations and the survivors, we observed community distrust with humanitarian assistance from Europe. In 2006, many migration associations were created, but the aid never arrived, and consequently people do not trust the NGOs and do not easily cooperate with international organisations. However, the families also do not trust the police or the government, due to fears of criminal charges, community shame and financial implications of repatriation. Therefore, in order to collect missing migrant information from families in Senegal, it is necessary to foster local liaison, to earn trust and create sustainable partnerships.

ICRC Senegal works with migrant families, and one of their aims is the creation of a national missing persons list. Although this might be a relatively easy task in

European countries, in Senegal the reality is very different; families only report missing children or victims of kidnapping to the authorities, otherwise communities do not trust the authorities and turn to alternative networks to try and find the missing person. These informal networks include the local Iman or Marabou, who search for news through mosque or spiritual connections. Nicolas Mendy, RCS Project Manager of Families of Missing Migrants (FMD), stated:

> *It is important to establish a relationship of trust between community leaders and the families of missing migrants. To help them, you need compassion and not judgment. It is a double suffering of losing one's child and becoming stigmatized, isolated, sometimes banished within one's community. If someone loses their child and you blame him for being responsible, you put him down.*[11]

The ICRC has been developing a AM-PM database adjusted to the reality of the migrants. The ICRC branch, Restoring Family Links (RFL), has also developed the project 'Trace the Faces', where families can try to find their missing family members online,[12] but this project is more focused on finding living migrants rather than collecting data for identification of bodies and, when the families of migrants who go missing in Senegal get in contact with the ICRC, psychosocial support is offered.[13]

In addition to ICRC Senegal, IOM is creating realistic databases of the missing migrants in Senegal and these data are available online via the Missing Migrants Project.[14] The IOM also wants to create a register of Senagelese associations related to migration; in Dakar almost all districts have such associations, but there is not an official list and they are not all supported by the government. With this data the IOM provides a useful tool for missing identification.

The local organisations who are currently collecting missing persons information directly from the families cannot share this data due to data protection regulations.

It is worth noting that clandestine migration from Senegal will not cease until those who remain have options for their future.

Use of facial identification and social media images

In West and Northern Africa, mobile phone coverage has been expanding in parallel to increased African migration to Europe, and mobile phones facilitate and shape migration patterns (Schaub 2012). Historically, mobile phone penetration as a

11 https://reliefweb.int/report/senegal/s-n-gal-pour-les-familles-de-migrants-port-s-disparus-le-soutien-de-leur-communaut

12 https://familylinks.icrc.org/euro

13 www.icrc.org/en/document/senegal-new-hope-families-missing-migrants

14 Personal communication with Jusselme Damien and Wilfried Coly from OIM Senegal, 11 August 2019.

percentage of population in Senegal increased from 0.001 per cent in 1994 to 99.9 per cent in 2015.[15] GSMA (2017) states that depending on the context, refugees may be highly connected, with 90 per cent of refugees in urban areas covered by 3G networks. There is evidence that mobile phones are a critical tool in migrant organisation, transportation and transnational communication (Zijlstra & Liempt 2017), and specifically for Senegalese migrants to the Canary Islands and Spain (Nyamnjoh 2013). It is still the case that people in wealthier countries have higher rates of internet use and smartphone ownership (Poushter *et al.* 2018). However, among people who use the internet, those in developing countries often turn out to be more likely than their counterparts in advanced economies to network via platforms like Facebook and Twitter (Poushter *et al.* 2018). Facebook states that 65 per cent of Facebook users are under 35 years (the likely migrant demographic) and 96 per cent of active users accessed the social media platform via mobile devices.[16] In 2013 (just before the peak of migrant deaths on Mediterranean crossings), Facebook revealed[17] that its users had uploaded more than 250 billion images and uploaded 350 million new images each day. To put that into perspective, that would mean that each of Facebook's 1.15 billion users uploaded an average of 217 images apiece. In 2016, Google announced[18] that more than 200 million people uploaded images to the application each month, of which 24 billion were selfies.

Selfies taken on mobile phones can be a useful source of material for identification. Olivieri and colleagues (2018) recommend the use of face data for the identification of dead migrants. Their study found that photographs and videos (social/candid scenarios) were frequently available from families as AM data along with recent images of the missing person retrieved from Facebook or other social media platforms. The authors also called for the use of 3D face capture at post-mortem examination as a valuable tool for later comparison with AM images.

Research has shown that surface details on the face, such as moles, creases, wrinkles, hair pattern and scars can be utilised for identification (Pierrard & Vetter 2007; Jain & Park 2009; Ramesha *et al.* 2010; Jain *et al.* 2012) and the morphological assessment of facial features is recommended by the Facial Identification Scientific Working Group (FISWG) for facial image comparison (FISWG 2020). Taphonomic literature demonstrates that faces change significantly with post-mortem processes including putrefaction, bloating, destruction and skeletonisation and research using 3D scan

[15] www.helgilibrary.com/indicators/mobile-phone-penetration-as-of-population/senegal/#:~:-text=Mobile%20phone%20penetration%20as%20a,than%20in%20the%20previous%20year

[16] www.omnicoreagency.com/facebook-statistics/

[17] https://mashable.com/2013/09/16/facebook-photo-uploads/?europe=true

[18] https://blog.google/products/photos/google-photos-one-year-200-million/

and photographic records has demonstrated early post-mortem changes to the face (Wilkinson & Tillotson 2012), including dehydration/shrinkage at the orifices (orbit, mouth and nose) in most (60 per cent) cadavers along with swelling at the periphery of the face in some (30 per cent) cadavers. Additional research using embalmed cadavers (Hadi and Wilkinson 2014) identified 20 facial creases that were resilient with bloating, suggesting that facial creases can be utilised for post-mortem identification. The use of AM and PM facial images for identification has been further evaluated (Caplova *et al.* 2017) using morphological comparisons and expert or student observers. The authors found a median recognition accuracy of up to 100 per cent was achieved across all observers depending on the image setup, indicating that comparison of facial images of unfamiliar dead and living persons may be used as a preliminary recognition method by a third person in the absence of other identifying markers.

Summary

The resulting recommended content for an online MDVI database has been an important outcome of this research.

In the Canary Islands, there has been no attempt to identify deceased migrants, although the local island judge has access to all cases and can approve the official identification for each migrant victim. To access any information about migrants and/or exhumation, a permit is required from the Secretary of the Ministry of the Interior and local governments, but this is a time-consuming, bureaucratic process making access exceptionally difficult. The recently established Medicolegal Institutes of the Canary Islands do now record the latest cases. There is no specific database for the identification of migrants in the Canary Islands and the most reliable database is from the ICRC border deaths (from 1990 to 2019), but this is not yet publicly available.

There are 249 unidentified migrant bodies in the Canary Islands, of which 166 are men, 7 women and 76 unknown sex. The main cause of death is 69.7 per cent drowning, 14.5 per cent dehydration, 9.2 per cent hypothermia and 6.6 per cent other causes. The published data for the island of Fuerteventura are 82 men, 2 women and 42 unknown sex, and 84.8 per cent of the cause of death is drowning, 12 per cent hypothermia and 3.2 per cent other causes. To compare this published information with local records, we used the island of Fuerteventura as a pilot. Information was requested from the municipal governments and was completed by counting marked niches in cemeteries. In total we counted 88 unidentified migrants, which differs from the published database by -38 people. However, we know that sometimes a single niche is utilised for several bodies, so there is a possibility that they are within the counted niches.

In Senegal, there is community distrust with humanitarian assistance from Europe, due to past disappointments, alongside distrust of the police or the government, due to fear, shame and financial concerns. Therefore, it is critical for future identification efforts to establish local liaison and sustainable partnerships, and to iron out data protection challenges associated with the necessary sharing of migrant/missing person data.

3D face capture and facial photography during PM examination provides a valuable resource for later comparison with AM images sourced from social media posts and selfies taken on mobile phones. Surface details on the face, such as moles, creases, wrinkles, hair pattern and scars are resilient features, even through early post-mortem changes, and can be utilised for morphological assessment and identification.

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