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A holistic approach to risk assessment

A groundbreaking multi-hazard climate and disaster risk assessment is helping authorities in Tonga to develop long-term responses to climate change

Authors Karen Barns, Tim Mote, Ed Rowe

1: The majority of Nuku‘alofa, the capital of Tonga, rises just 2m above sea level and is highly vulnerable to pluvial flooding

On the evening of 15 January 2022, the underwater volcano Hunga Tonga-Hunga Ha‘apai in the South Pacific erupted with a force estimated by NASA to be hundreds of times more powerful than an atomic bomb. The blast sent shockwaves and tsunamis across the region, and within a few hours the Polynesian archipelago of Tonga was blanketed by a plume of ash, steam and gas.

One uninhabited atoll was completely obliterated and entire towns on the other islands, including the capital city Nuku‘alofa on the main island of Tongatapu (65km south of the volcano), were inundated by waves. This resulted in the destruction of the only fibre-optic cable connection to the rest of the world. As Tongan officials, volunteers and communities scrambled to cope with the impact, disaster managers and government decision-makers moved swiftly to assess the scope and scale of humanitarian need, and the damage to housing, workplaces and infrastructure.

The repercussions of catastrophic events of this magnitude are complex to comprehend, but officials were fortunate on this occasion to be able to draw on a comprehensive, multi-hazard disaster risk assessment of Tongatapu, completed just seven months before the eruption took place.

Commissioned by the Government of Tonga and the Asian Development Bank (ADB) and carried out by Arup, the first-of-its-kind study and associated geo-referenced database was unrivalled in its scope, covering building, water, energy and road assets in the island’s built environment. It included 50,000 buildings and infrastructure assets, and a wide range of hazards such as flooding, coastal inundation, tropical cyclones, seismic and tsunami hazards and the effects of climate change. Direct financial losses associated with each hazard scenario in the database, as well as average annualised losses by hazard and sector, were also quantified to help inform authorities’ crucial decisions and planning, both for today and for the future.

Natural disasters

Tonga is no stranger to natural disasters; the kingdom ranks third out of 181 countries in the World Risk Index 2021, after Vanuatu and the Solomon Islands. The majority of Nuku‘alofa rises just 2m above sea level and is highly vulnerable to pluvial (surface) flooding caused by heavy rainfall, and to coastal flooding from extreme sea level rise, cyclone-induced storm surge and tsunami inundation. Some agricultural, ecologically sensitive and other marginal areas are at elevations below high tide, and experience frequent inundation. Exposure is such that around 20,000 people are regularly affected by flooding on the island, a figure that is expected to increase in the future, as a result of climate change-induced sea level rise.

Keen to get a better understanding of climate and disaster risks to help inform its future planning and investment decisions, in 2020 the Government of Tonga and ADB commissioned Arup to undertake a study. The assessment

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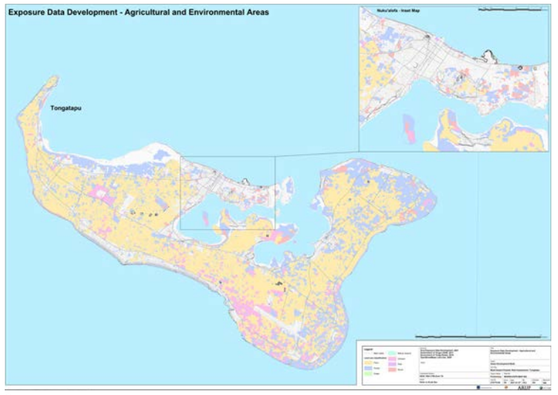
2: The geo-referenced database Arup created covers building, water, energy and road assets

3: The analysis included 200km^2 of agricultural and environmental areas on Tongatapu



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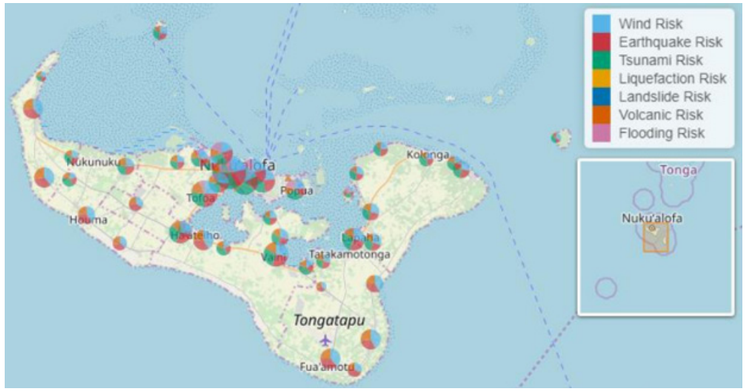
was carried out by a global team of 20 Arup specialists who also collaborated with New Zealand-based firm eCoast Marine Consulting, engineering services firm Kramer Ausenco, ADB and the Government of Tonga.

ADB and the World Bank have supported infrastructure projects in Tonga for many years, but risk assessments were typically carried out on a project-by-project basis and focused on a single asset or a particular hazard, such as flooding.

Investments in resilience measures worldwide are typically decided based on estimates of future losses, but until losses are experienced in reality, investors can be hesitant to supply funding. Arup worked closely with ADB and the government on an innovative plan aimed at circumventing this issue by taking a holistic approach, providing accurate and actionable data covering the full range of assets and hazards to ensure confidence in future investment decisions.

The project analysed in excess of 50,000 buildings, power and water assets, more than 1,000km of roads, and over 200km^2 of agricultural and environmental areas on Tongatapu to identify risks. Assets were plotted against 220 different



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4: Assets were plotted against 220 different hazard scenarios

5: The project analysed more than 50,000 buildings and power and water assets to identify risks

hazard scenarios, covering earthquakes, windstorms, tsunamis, rainfall and coastal flooding, to model the impact both with and without climate change. Climate and disaster risks to assets and population across the atoll were communicated in terms of direct financial loss, i.e. the cost to repair or replace damaged assets. This normalised approach makes it possible to directly compare the economic impact of different natural hazards and scenarios; for example, losses quantified under today's climate for tropical cyclone wind hazard can be compared with losses estimated for a future climate-influenced scenario for rainfall flooding.

Data is critical when it comes to risk assessment and the study exploited a range of international, regional and national datasets. Detailed records were available for some hazards and assets, but others were less robust and rigorous, putting an emphasis on field survey work and modelling to ensure a consistent approach.

Field surveys and machine learning

In the midst of the Covid-19 pandemic and the associated restrictions on travel, Arup remotely trained local engineers and surveyors to carry out field surveys. At the start of each phase of the project, a series of interactive training workshops were held by videoconference, instructing the recruits how to use tablet computers pre-loaded with the survey software and forms.

A subset of around 2,000 buildings and structures on the island had previously been visited and assessed, and a further 8,000 were surveyed by the Arup team. Limitations on available time and resources informed the decision to use machine learning to determine values of assets that were not visited. Notably, 50% of buildings with a plan area greater than 20m^2 had no attributes. So, a probabilistic method was developed to statistically assign and populate missing data, using estimated values through an iterative machine learning process.

Various validation exercises were applied to data sources during the project to ensure consistency, with a particular focus on buildings and roads. For example, street view software was used to validate data received from the Pacific Catastrophe Risk Assessment and Financing Initiative, and to quality-check data received from in-country surveys.

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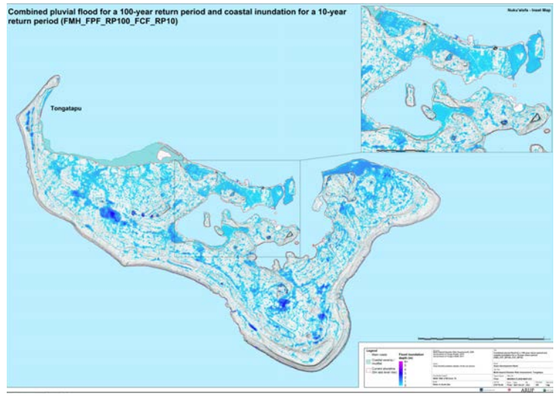
Key results

Arup's study has comprehensively quantified the potential impacts of the island's vulnerability to hazards, particularly by considering the influence of climate change for the first time. Pluvial flooding was found to be the most significant driver of risk for frequent events. However, with consideration of the rarer events, seismic hazard poses greater risk. Average annual losses for pluvial flooding were US$130m, followed by seismic at US$58m, wind at US$4m, and then coastal inundation at US$3m. Discrete rural areas and parts of the capital were found to be more susceptible to pluvial flooding, in terms of the percentage of land flooded.

Arup's research revealed that rarer hazard events with longer return periods saw significantly larger losses than shorter, more frequent hazard events for wind and seismic activity. However, this was far less significant for pluvial flood, coastal inundation and tsunami hazards. For example, a 200-year return period seismic event resulted in a relative loss of 18.7% (financial loss as a percentage of the total asset value), which was significantly higher than the relative loss of 0.8% for a 10-year return period. A 200-year return period pluvial flood event resulted in a relative loss of 7.1%, which was only slightly higher than the relative loss of 4.0% for the 10-year return period event.

Sea levels have risen 6.4mm per year on average around Tonga in the past decade – well above the global average – and Arup's team modelled the risk of inundation for future rises of 0.5m, 1m and 2m. Increased intensity of rainfall was also considered for future climate scenarios. Permanent losses from sea level rise were significant compared with all other return period scenarios, ranging from 6% of the total asset value in a 0.5m scenario, to up to 50% in a 2m scenario. Arup found that a 1m scenario would see tidal inundation of 25% of buildings, 11% of roads, 16% of water and 29% of power infrastructure. If considered permanent losses, this would be equivalent to 10 times the losses incurred by Tropical Cyclone Gita in 2018, the most intense tropical cyclone to hit Tonga since reliable records began. However, the report found that increased urbanisation and/or new flood protection infrastructure would have a major impact on expected losses, before any of these scenarios arrive.



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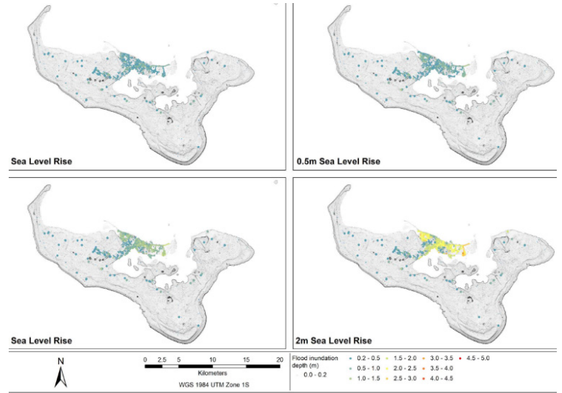

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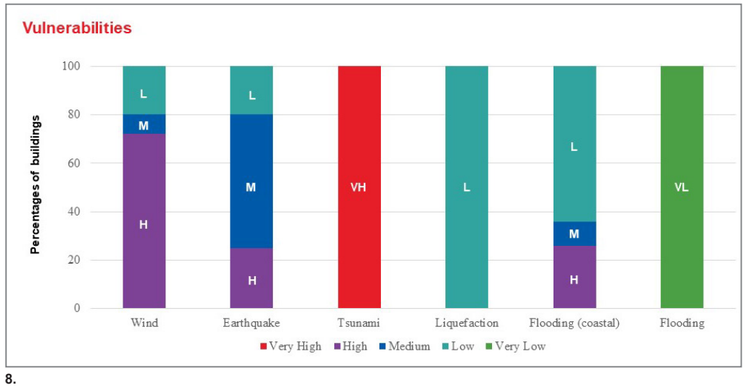

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6: Pluvial flooding was found to be the most significant driver of risk for frequent events but, with consideration of the rarer events, seismic hazard poses a greater risk

7: Arup modelled the risk of inundation for different future sea level rises

8: The study comprehensively quantified the potential impacts of the island's vulnerability to hazards, including the influence of climate change for the first time

Informing investment decisions

The research highlights the importance of differentiating between the probabilistic occurrence of a single hazard event, and gradual impacts from projected sea level rise. For example, the predicted 19% loss of total asset value under a 200-year seismic scenario is similar to the 25% permanent losses associated with a future scenario with 1m of sea level rise. Tonga's government can use

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9: Sea levels have risen 6.4mm per year on average around Tonga in the past decade – well above the global average

this information to inform investment decisions, such as upgrading buildings to resist earthquakes, which may reduce losses associated with hazard events under today's climate, or instead invest in coastal defences and management solutions over time, to address sea level inundation under a future scenario.

A number of tsunami scenarios were modelled, considering different magnitudes of earthquake source and various maximum wave amplitudes. The scenario with the highest maximum amplitude – a 9.0 magnitude earthquake with a 6.2m offshore wave amplitude – reported losses equivalent to 10% of the total asset value assessed across Tongatapu. These were concentrated in Nuku'alofa and towns surrounding the lagoon.

The many insights revealed in Arup's assessment will help ADB and the Government of Tonga take a more upstream perspective on climate change, based around resilient development and adaptation. This should result in the gradual development of safer areas and investments in new assets outside the highest-risk areas that are also resilient to natural hazards.

Some findings have already fed into the disaster and climate risk assessment for a proposed major bridge crossing Tongatapu's central lagoon. Data on tsunami wave loading and seismic activity fed into a structural assessment of the proposed bridge design, and the anticipated impacts of climate change on local communities and road infrastructure supported due diligence on the investment in the project. The research was also presented at the United Nations Climate Change Conference (COP26), held in Glasgow in November 2021.

Immediate impact

The devastation wrought on Tongatapu by the volcanic eruption gave unexpected relevance to Arup's work, and the Government of Tonga was quick to share the data with researchers and bilateral, regional and multilateral organisations keen to help address the impacts.

Volcanologists at the University of Canterbury and the National Institute of Water and Atmospheric Research in New Zealand produced estimates of the thickness of ashfall deposits for the entire island, including detailed maps for the energy, water, road and agricultural sectors, using data from the initial assessment. This covered preliminary predictions of damage and an advisory to the government on clean-up operations. The World Bank also produced a Global Rapid Post-Disaster Damage Estimation, providing specific information on direct disaster losses in the weeks following the eruption.

It's not often that research has such an immediate impact, helping a nation to navigate its way out of catastrophe, and Arup is honoured to have been part of the process. The firm believes the same risk assessment model can be rolled out across other nations, and similar projects are already being considered for Timor-Leste and the Cook Islands.

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Project credits

Clients Government of Tonga, Asian Development Bank

Collaborators eCoast Marine Consulting, Kramer Ausenco

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Transforming women's mobility in Ireland

New insights into women's travel patterns are informing the future design of sustainable transport for all

Authors Rebecca Chau, Léan Doody, Alannah McCartney, Orla O'Halloran

Transport is often seen as gender-neutral, providing benefit to all equally. However, growing international research highlights that this is not the case. Today, women often have different travel needs from men, including more complex trips, heightened safety concerns and additional caring responsibilities. Yet, historically, transport has not been designed with those differing requirements in mind.

Transport Infrastructure Ireland (TII) is the agency delivering transport infrastructure and operating public transport systems in Ireland. It wanted to understand the different travel needs of women and the reasons why they rely more heavily on cars, in a bid to influence future transport policy and encourage a shift to more sustainable modes of travel.

Arup has a long-standing relationship with TII, working in partnership on a wide range of projects including tolling strategy, network operations, governance, standards, sustainability planning, decarbonisation, active travel, and infrastructure design and planning services. TII engaged the firm to carry out the first-ever study to investigate women's travel needs and behaviours in Ireland. Arup worked closely with TII, gender equality specialist Kelly Saunders and insights agency Spark, to develop a research methodology giving rich insights into women's travel experiences.

The 'Travelling in a Woman's Shoes' study highlighted the lived experiences of women in Ireland through data and real-life stories, offering a fresh perspective on discussions about equal access to public transport. Bucking global trends, women in Ireland rely more heavily on car travel, with significant caregiving responsibilities, safety issues and lack of equality of access to quality services acting as drivers of car dependency. The research found that 55% of women avoid public transport after dark (compared with 35% of men). One bad experience can fundamentally alter a woman's perception of different transport options. This can be something that happened to them or a friend, or an incident they see in the news.

The report identified opportunities for improving women's travel experiences, enabling greater use of public transport and contributing to the overall aim of decarbonising Irish transport. This study is a step towards creating a more equitable travel experience and is informing discussions about future policy and infrastructure design, to encourage more sustainable mobility for all.

1: The research found that 55% of women avoid public transport after dark

Context

Equality for girls and women depends on mobility, as this gives access to quality education, higher-paying jobs, social and political life, health services and leisure. Poor access to transport significantly hinders their participation in the labour market and so having transport equality can reduce gender inequalities, including helping to close the gender pay gap.

Unsafe or traumatic travel experiences can lead to absenteeism and decreased productivity among women. When they feel empowered and safe to walk, cycle, use public transport and car-share, this reduces car dependence, accelerating the transition to net zero. A safer, more equitable transport system also improves