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# A Survey of Disaster Risk and Resilience in Small Island States

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<http://dx.doi.org/10.5772/intechopen.80266>

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## Abstract

This paper surveys the conceptual framework of disaster risk that relies on its associated components of hazard, vulnerability and exposure. How we measure these risks depends on how we define disaster risk and its components. We focus on the implication and applicability of available conceptual frameworks of disaster risk on small and low-lying islands in the Pacific. We examine some of the available measurements of these disaster risks as they are imperative to the formulation of appropriate disaster risk reduction (DRR) policies for Tuvalu. Though there are diverse views on these definitions in different disciplines, we can capitalise on their commonalities to frame disaster risk models. Here, we intend to use the findings and set a pathway for potential research and to contribute into building resilience, reducing DRR and improving responsiveness to the impact of climatic disasters in Pacific Islands.

**Keywords:** disaster risk, hazard, exposure, vulnerability, resilience

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## 1. Introduction

Natural disasters such as cyclones, earthquakes, floods, tsunamis, storm surges and heat-waves have distressed the lives of the people around the world. The Asia-Pacific region is the most highly exposed to disasters in the world, with the highest overall disaster-related deaths, representing 75% of global mortality for the years between 1970 and 2011 [1]. Changes in the climate, sea level rise and the intensity of climatic disasters like tropical cyclones<sup>1</sup>,

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<sup>1</sup> According to [2] small countries are more vulnerable to windstorms than other countries which can lead to a decline of 3% in GDP per capita.

droughts and floods have an extremely negative impact on economies, communities, households, people and physical assets [3, 4]. Developing countries are especially vulnerable to these impacts due to their underlying limited natural endowments, economic constraints and limited adaptive capacity [5]. Small Island Developing States (SIDS) are especially vulnerable to large-scale economic and environmental disasters, whereby their geography and size make them highly exposed and vulnerable, with less capacity to respond [6].

In the Pacific region, climate-related disaster risk has been increasing in the past decades, most likely because of increased exposure of people and economic assets. Within the Pacific SIDS, the smaller island states<sup>2</sup> like of Tuvalu and Kiribati consist of low-lying<sup>3</sup> stretches of atoll islands that are most vulnerable countries to climate change, sea level rise and climatic disasters<sup>4</sup>, particularly to destructive cyclones with associated storm surges that can easily flood large parts of the islands. By United Nations (UN) standards, smaller island states are mostly categorised as least developed countries (LDCs). Their vulnerability, exposure and economic status slow their graduation from being LDCs. We focus on Tuvalu and Kiribati as they are low-lying atolls and sovereign states within the Smaller Pacific Island States. In Tuvalu, natural disasters such as cyclones with associated storm surges often flood some islands, inflicting significant damage on the livelihoods and physical assets of the population, while imposing adverse effects on the economy and ecosystems.

The cyclone of 1972 is the worst event ever experienced by Tuvalu.<sup>5</sup> However, there have been other noticeable strong storms in the recent past. A more recent event, in 2015, was a distant cyclone (about 1000 km away) called Tropical Cyclone Pam (TC Pam), affecting the islands of Tuvalu with estimated damage and losses of 10% of GDP [9]. The changes in weather patterns and the threat of rising sea levels due to climate change further aggravate these threats.

This inquiry reviews the growing body of the recent literature on disaster risk and associated components influencing it. We aim to understand the concepts of disaster risk in order to recognise its challenges, opportunities and implications for SIDS, particularly low-lying islands like Tuvalu. Through this, we can acquire ideas of what is needed to improve disaster risk management (DRM) and ways to advocate for and strengthen disaster risk reduction (DRR) efforts. Reviewing the literature on disaster risk will also situate this research in its broader context, in order to provide direction for future research in this growing field, with the focus on small island states.

<sup>2</sup> Smaller island states classified under the Pacific Islands Forum comprise Cook Islands, Federated States of Micronesia, Kiribati, Marshall Islands, Nauru, Niue, Palau and Tuvalu.

<sup>3</sup> Ref. [7] stated that the whole land in Tuvalu lies below 5 m.

<sup>4</sup> Vulnerable to natural disasters in per capita terms.

<sup>5</sup> Ref. [8] stated that 'In October 1972, cyclone "Bebe" hit Tuvalu, killing several people destroying millions of dollars worth of property. The capital atoll of Funafuti was engulfed by waves from both the ocean and lagoon side, with a huge 19 km long, 30–40 m wide and 4 m high embankment (called a "storm ridge") being formed as a consequence of the waves moving huge quantities of sediments. The storm damaged houses, infrastructure, boats, coconut trees, the reef flats and caused extensive scouring of the islets in the atoll.' (See <http://www.janeresture.com/hurribebe/hurricanebebe2.htm> for full details of the impact of cyclone Bebe on Funafuti Island, including documented stories from seven people who experienced the devastation of the event).

## 2. Disaster risk

Natural disasters affect people worldwide, causing losses and damages. Climate change and its influence on the frequency and intensity of natural disasters have been part of the emergence of the new branch of economic research on the economics of disasters.

Ref. [10] defined disaster as ‘a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources’. Here, disasters are being described in relation to exposure, vulnerability and coping mechanisms. The definition of disaster risk reflects on the meaning of disasters; disaster risk is not only the likelihood of a disastrous event but also often associated with mechanisms that inflate the impacts of such events. Particularly, disaster risk is a function of three interlinked components: hazard, exposure and vulnerability [11]. By definition, [10] refers to disaster risk as ‘the potential disaster losses, in lives, health, status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period’.

Refs. [12, 13] elaborate on the framework of the ‘dual-faced’ character of nature that presents a set of possible opportunities and possible hazards, emphasising that disasters are not solely driven by the natural environment but also influenced by human activities, that is, they are the product of political, social and economic environments. They also introduced a conceptual framework that defines and explains the relationship between risks, hazards and vulnerability. This pressure and release (PAR) framework illustrates that the intersection of hazard, vulnerability and coping and recovering capacities correspond to disaster risk. Moreover, [13] advanced the framework of ‘progression and vulnerability’ comprising of root causes, dynamic pressures and fragile livelihoods and unsafe locations.<sup>6</sup> This framework reflects the fact that limited access to resources that allow for risk reduction impedes coping and recovery mechanisms for hazards. Nevertheless, disaster risk and its underlying components (hazard, exposure and vulnerability) are changing in relation to the changes in the environment and political, economic and social aspects of society [11].

### 2.1. Hazard

Hazard is widely recognised as an extreme natural event or process [13], a potential harmful event or process [4], or a hazardous phenomenon [14]. In the past, natural hazards and their characteristics were the main focus of discourses relating to disasters.

In addition to naturally occurring hazards, the evolution of the way we look at disasters has unfolded new components of disaster risk and extended its scope. [10] refers to hazard as ‘a dangerous phenomenon, substance, human activity or condition that may cause loss of life,

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<sup>6</sup>‘Root causes’ in this context centres around existing social, economic (e.g. distribution of resources, wealth and power) and political structures. ‘Dynamic pressures’ concerns with societal deficiencies (relating to economic opportunities) and lack of macro forces. Unsafe conditions are specifically associated with the situation facing vulnerable people in a given time and place.

injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption or environmental damage'. Recently, [11] defined hazard as the likelihood and intensity of a potentially destructive natural phenomenon, such as ground shaking induced by an earthquake or extreme winds associated with a cyclone.

Generally, hazard is interpreted as an influence that can adversely affect a system's valued attributes. Ref. [15] noted that there has been a paradigm shift in the development literature on hazards and disasters, from assessing hazard to analysing vulnerability and building community resilience.

## 2.2. Exposure

Ref. [11] defined exposure as the location, attributes and value of people and assets (such as buildings, agricultural land and infrastructure) exposed to the hazard. Ref. [4] broadly refers to exposure as the external environment that determines the shocks to which a system is subject. Ref. [16] postulated that exposure is the 'degree, duration, and/or extent in which the system is in contact with, or subject to, the perturbation'. Ref. [17] described exposure more discretely by referring to it as 'the likelihood that an individual in a given location is exposed to a given type of climate-related hazard event over a certain period of time'. They also estimated population exposure to climate-related hazards (e.g. cyclones, droughts and floods) using gridded datasets, with which they calculated the population exposure by the relative hazard frequency in a certain area weighted by the population density frequency. As a result, they ranked countries by population exposure to these extreme events.

Ref. [14] refers to exposure as the location of people, production, infrastructure, housing and other tangible human assets in hazard-prone areas. Ref. [10] defined exposure as 'people, property, systems, or other elements present hazard zones that are thereby subject to potential losses'. The poor are exposed to disasters [18], and, further, poor people are often, but not always, more exposed to hazards [19]. Ref. [20] developed an exposure model for hazard risk assessment from a Country Disaster Risk Profile (CDRP) which complements vulnerability and hazard models.

## 2.3. Vulnerability

Ref. [21] posited that the scientific use of 'vulnerability' has its roots in geography and natural hazard research but has become a central concept in many other research contexts. Vulnerability is defined as the potential extent to which physical, social, economic and environmental assets may become damaged or disrupted when exposed to a hazard event [11]. Vulnerability is a complex term with no consensus on its meaning, though it tends to include various factors that have the potential to be damaged or harmed by a hazard event. For instance, on a physical scale, it refers to physical vulnerability when looking at the level of damage sustained by built structures due to a hazard event. On the social level, it refers to 'social vulnerability' (also known as 'socio-economic vulnerability' or 'socio-economic resilience') where damage relates to livelihood and other social factors that influence a community's ability to respond to, cope with and recover from a disaster [11]. Social vulnerability can affect the number of casualties, the loss or disruption sustained and a community's subsequent recovery time. Similarly, [10] defined vulnerability as 'the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard'.

Vulnerability is often seen as a potential for weakening the capacity of an individual or group to face, cope, resist, respond to and recover from the impacts of natural and anthropogenic hazards. Ref. [22] comprehensively outlined the analysed vulnerability framework and its components—exposure, sensitivity and resilience—which are linked to dynamic factors beyond the system. The degree of vulnerability and capacity to respond to and recover from disasters are often determined by physical, economic, social and political factors. Through this, vulnerability is often connected to poverty. To better respond to these disasters, there is a need for reducing hazard impact (through preparedness, mitigation, prediction, etc.), building and strengthening capacities to resist and cope with hazards and attempting to reduce sources of vulnerability (e.g. through poverty reduction, good governance, equality, accessibility to resources and livelihoods).

Ref. [23] argued that the extent of disaster risk depends on natural hazards and vulnerability. They also support the argument that there is a higher level of vulnerability in the urban areas due to higher population density. As poorer households tend to reside in riskier urban areas [24], they are more likely to face rising costs and relatively higher losses and damages during disasters. Normally, the poor are more affected due to economic and social attributes [12]. At the macro-level, [23] further illustrates the notion of the 'inverted U' relationship between economic development and disaster vulnerability, indicating that middle-income countries are specifically vulnerable to natural disasters. Ref. [25] strengthened the link between poverty and disaster for Bangladesh arguing that the poor are not only more vulnerable to natural events but also have less ability to access resources due to factors such as social and political identity, kinship, social networks, financial capacity, political connections and rivalry. They argued that the dynamics of livelihoods, local power, resilience and cyclones are interconnected.

Ref. [26] examined climate justice for SIDS like the Caribbean islands and argued that factors driving vulnerability pointed to centuries of economic neglect and political marginalisation that are strongly related to communities' socio-economic characteristics, geographic locations, heavy reliance on land-based resources and the capacity to adapt to climate change. Refs. [26, 27] stressed that vulnerability to negative impacts of climate change is partly a function of different coping and adapting capabilities of various groups of people in developing countries. Ref. [26] further argued that vulnerability to climatic impacts is inherently developmental as differentiated levels of exposure and sensitivity to natural hazards are partly created by social and economic inequalities, as well as accessibility of land-based resources, assets and government support. Ref. [27] strengthened the notion that vulnerability and capacities to cope with natural hazards differ due to differential accessibility to resources (e.g. natural, physical, human, social and political).

On the other hand, economic vulnerability is well documented in the literature from both conceptual and empirical viewpoints. Most studies in this stream point to the small island states as highly vulnerable to exogenous shocks due to their high degrees of economic openness and export concentration [28]. SIDS are most vulnerable to disaster risks due to increasing intensity of cyclones and sea level rise. Ref. [29] recognised the vulnerability of SIDS to disasters and the lack of economic resilience arising from the relative inability of these countries to face forces of scales out of their capacity to deal with independently. Ref. [30] emphasised that measuring risks and vulnerability is imperative in promoting disaster resilience in hazard-prone areas.

## 2.4. Resilience

Refs. [16, 31–33] all believed that the literature on resilience emerged from the ecology discipline, as an offspring of an influential paper by [34] called ‘Resilience and stability of ecological systems’. [15] outlined the various definitions of community resilience. Ref. [35] argued that definitions reflect on the nature of a system (e.g. ecological, economic, social or political). For instance, the literature and different organisations have their own definitions for disaster resilience. Ref. [33] proposed a framework called the Disaster Resilience of Place (DROP) model and emphasised that there is more to articulate about the relationship between vulnerability, resilience and adaptive capacity. They distinguish ‘vulnerability’ as the characteristic that creates the potential for harm and ‘resilience’ as the ability to respond to and recover from disasters. Similarly, although [28] argued that risk is determined by the two elements, namely, exposure and coping ability, they associate exposure to vulnerability and coping ability to resilience.

Many terms were used to describe the various efforts to reduce risk, namely, preparedness, public awareness, prevention, adaptation, resistance, mitigation, response and so on. Ref. [10] refers to resilience as ‘the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions’. With the increasing global threat of climate change and associated disasters, measuring resilience has increased in popularity with efforts attempting to build resilience to climate change and disasters. Consequently, many papers have emerged with definitions, concepts and indicators for measuring resilience. These concepts are often complexly inter-related. Other studies by [36] identified economic indicators of resilience based on impact, outcome, output and input.

Furthermore, [37, 38] compared ‘economic vulnerability’ and ‘economic resilience’ to explain the phenomenon known as the ‘Singapore Paradox’.<sup>7</sup> This is a phenomenon based on the fact that even though the small island state of Singapore is highly exposed to exogenous shocks, still they achieved and attained high levels of economic growth and GDP per capita.<sup>8</sup> The importance of economic resilience to disasters was highlighted by [36] as an enabler of many broader development goals.

Building resilience requires a clear concept of ‘resilience’ itself. Reflecting on the complications of civil society and the thinking behind disasters in relation to society, it is not surprising that various disciplines have diverse definitions of ‘resilience’. However, there are commonalities apparent in these definitions, and this is fundamental in establishing a resilience paradigm. With more clarity and consensus on the definitions, disaster resilience can be more achievable with less confusion. Consequently, an evolution in defining ‘resilience’ has steadily enhanced the way we conceptualise disaster resilience.

<sup>7</sup> See [39] for more discussion on ‘economic vulnerability’ and ‘economic resilience’.

<sup>8</sup> This case can be explained by its ability to face external shocks through building resilience. Unlike other isolated small island states like Tuvalu and Kiribati, Singapore has geographical advantages (port, location is heavily populated in the region) as a trade centre, with the presence of multinational companies on its shores. Therefore, Singapore has the potential to build economic resilience.

On a more practical level, [40] employed a resilience index measured as a ratio of preparedness (capacity to overcome a disaster) to vulnerability (exposure towards a disaster). Ref. [18] revealed the 3D resilience framework, whereby resilience arises as a result of the three capacities, namely, absorptive, adaptive and transformative capacities. On the other hand, [41] modelled infrastructure resilience by quantifying resilience as a function of absorptive, adaptive and restorative capacities. They refer 'absorptive' as the capacity of a system to absorb or withstand the impact of disruptive events and minimise the consequences, 'adaptive' as the capacity of a system to adapt and overcome a disruption, and 'restorative' as the capacity of a system to repair and restore from a disruption.

### 3. Measurements of disaster risk

In the economic community, there are available econometric methods to measure disaster risk (or disaster impact). Most use time series, cross section and panel data to identify the relationship of explanatory variables on disaster risk (or disaster impact). Ref. [42] showed how the impacts of disasters can be measured by referring to a model of the form:  $Y_{it} = \alpha + \beta X_{it} + \gamma DIS_{it} + \varepsilon_{it}$  where  $Y_{it}$  denotes disaster impact of interest,  $DIS_{it}$  is a measure of the immediate impact of disaster on country  $i$  at time  $t$ ,  $X_{it}$  is the typical vector of control variables affecting  $Y_{it}$  and  $\varepsilon_{it}$  is the error term. They also show other extended models using other estimation methodologies.

Other studies like [43, 44] suggested that disaster risk is a function of hazard, vulnerability and capacity. However, discourse surrounding the definition of 'resilience' compared to 'capacity' has resulted in diverse perspectives and formulations of disaster risk. Following definitions from [10, 44] modified the formula proposed by [43] arguing that disaster risk should be a function of natural hazards, vulnerability, exposure and resilience. They argued that this modification better reflects on the underlying purpose of disaster risk reduction (DRR) in reducing vulnerability and exposure to hazard while building resilience for potential impacts. Measuring of disaster risk in this manner has become popular with the increasing intensity of disasters and associated costs (loss and damage) over time, which has in turn generated the emerging focus of research in this area followed by extensions in definitions and concepts. Ref. [45] breaks down the effects of disasters into direct damages (affected assets) and indirect losses (affected flow of goods and services).<sup>9</sup> These developments, extensions and interactions (capturing resilience, adaptability, responses and other factors) are useful in identifying areas in need of building resilience for disasters. This has made measuring and building of resilience an essential tool for reducing disaster risk.

The conceptual framework for risk under the PAR framework [12] discussed earlier outlines an equation of the form where  $Risk = Hazard \times Vulnerability$ . Nevertheless, an extension was formulated based on the [46] expressing the crucial role of natural hazards, exposure and vulnerability in measuring disaster risk. This widely used formulation within the disaster risk

<sup>9</sup>See [42] for more discussion on natural disasters and the economy.



community is simply expressed as  $Risk = Hazard \times Exposure \times Vulnerability$ . They translate disaster risk as the multiplicative function of hazard, vulnerability and exposure. Typically, it is expressed as  $Y_i = \alpha_0 + \beta_1 Hazard_i + \beta_2 Exposure_i + \beta_3 Vulnerability_i + \varepsilon_i$  for cross-sectional data. On the other hand, it can be extended to  $Y_{it} = \alpha_0 + \beta_1 Hazard_{it} + \beta_2 Exposure_{it} + \beta_3 Vulnerability_{it} + \varepsilon_{it}$  for panel data, where the dependent variable  $Y_{it}$  is typically represented by direct impact on either people (losses or lost lives) or assets (e.g. direct damage costs) as a result of a disaster on unit  $i$  at time  $t$ , while the explanatory variables of  $Hazard_{it}$ ,  $Exposure_{it}$  and  $Vulnerability_{it}$  are vectors of characteristics and measures that represent them. Recently, [47] extended the risk framework to capture both risks to assets and well-being by including a measure of socio-economic resilience in his risk assessment.

#### 4. Policy implications

Ref. [5] stressed that people previously affected by natural disasters are more risk averse than those unaffected. For small and low-lying islands like Tuvalu, preparedness for tsunamis is a complex problem as there are no high grounds worthy to be safe zones. The option of resettling or moving to safer places is almost impossible in Tuvalu, because of limited lands and economic and legal constraints. Most of the people live close to the coasts, not by choice but by the limited lands available.<sup>10</sup> For Tuvalu, it is much safer in the outer islands than in the capital island Funafuti (urban) since the elevation is a little higher, there is more land area, and they are less populated. But, most economic opportunities are in Funafuti.

Transferring financial risk through insurance does not exist in Tuvalu, but this is recognised as a financial resilience tool to extreme climatic events like cyclones [48]. Ref. [49] points out the importance of having better institutions in a country in lowering human and economic losses from natural disasters. He also postulates on the non-linear relationship between economic development and economic disaster losses. Social networks at the local level are vital for community resilience and recovery from disasters [50–52]. Often, community resilience is a foremost response to disaster impacts [53] and also acts as informal insurance after disasters [54]. For small islands like Tuvalu, where almost everyone knows their neighbours (relatives and friends) and people on their islands, local social networks and communities are central to disaster response and recovery efforts.

It is commonly agreed that climate change will displace millions of people worldwide. However, low-lying islands in the Asia-Pacific are at the forefront of both disasters and environmental change. Migration is the last option when security and the lives of the people are at high risk. Despite this global problem, there are no provisions under international laws to protect those who will be forced to migrate due to environmental causes. Ref. [55] distinguish ‘economic migration’ from ‘distress migration’ based on household resources, capabilities and decisions. ‘Migration with dignity’ is a concept often advocated by some Pacific leaders [56, 57].

Migration is seen as a survival strategy for people experiencing environmental problems, but not the only available strategy [58]. Ref. [59] outlines three options: stay and do nothing

<sup>10</sup>With overall land area of 25 km<sup>2</sup> and a population of 10,000 people.

and accept the costs, stay and mitigate the changes, or leave the affected areas. In relation to ecological conditions, migration decisions are complex and linked to multiple vulnerabilities; therefore, relocation can be the only sustainable option as an adaptation strategy [60].

## 5. Applicability of the disaster risk model on SIDS

The components of disaster risk—hazard, exposure and vulnerability—interact to determine very high risk in most SIDS. Increases in the levels of these components will increase total risk and lead to greater damages and losses associated with disasters. Understanding and quantifying these risks in order to measure and propose risk reduction options are therefore of vital importance.

The two types of extreme events that often devastate the livelihoods of the people in SIDS are tropical cyclones and droughts. Throughout the last decade, SIDS in the Pacific has experienced some of the most severe disasters in its history. To our knowledge, these were some of the few declared disasters by the government of Tuvalu since TC Bebe in 1972.<sup>11</sup> Further, the intensity of disaster events has been increasing, as observed in the recent TC Pam, which caused devastation even though it was a distant cyclone to low-lying islands like Tuvalu and Kiribati. Likewise, these islands experienced one of the longest droughts in 2011. These extreme events were evaluated to be national disasters for Tuvalu that forced the government to declare states of emergencies.

For these small and low-lying islands, exposure at the household level can relate to the distance of the household from the coast and its elevation, as these are likely to be some of the determining factors of disaster risk given the size of the islands and low ground elevation. While these small and low-lying islands are considered very exposed to hazards because of their geographical setting, some islands may be more vulnerable and exposed because of combinations of other factors. For instance, apart from distance to the coast and elevation, some islands have lagoons and islets that can serve as shields during strong winds, while others have none. The width of the island is another factor: for instance, the capital island Funafuti is no more than 900 m in width, with an average of 347 m on average in land width for residential areas. The impact of a cyclone depends mostly on its distance from the islands and its trajectory, but the above are some of the extra characteristics and challenges facing small and low-lying islands that need to be included in defining exposure to disasters.

A vulnerability index for the natural environment called the Environmental Vulnerability Index (EVI) was developed by the South Pacific Applied Geoscience Commission (SOPAC) and the United Nations Environmental Programme (see [61]), whereby most of the atoll islands including Tuvalu were classified as extremely vulnerable countries (see [62]). Most low-lying Pacific Islands are least developed country (LDC), and as such, they have always been vulnerable to climatic disasters, mainly due to their geographical settings and economic

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<sup>11</sup> TC Bebe track passed over Tuvalu, specifically between the islands of Funafuti and Nukulaelae, based on the tropical cyclone map by the Australian Severe Weather at [http://www.australiasevereweather.com/tropical\\_cyclones/1972\\_1973/jtwt/tropical\\_cyclone\\_bebe.htm](http://www.australiasevereweather.com/tropical_cyclones/1972_1973/jtwt/tropical_cyclone_bebe.htm).

characteristics. Population density on the capital islands, for instance, Funafuti of Tuvalu where the population density is 2220 people per square kilometre, is another issue.<sup>12</sup> The constant increasing population density in hazardous areas [49] is evident on Funafuti with the population distribution of 42.5% (in 1991), 47% (in 2002) and 57.2% (in 2012).<sup>13</sup> However, socio-economic characteristics such as access to resources, communications and transportation (particularly for those in the outer islands) make some people more vulnerable than others.

Ref. [64] measured the burden of disasters on PICs using two global datasets [Emergency Events Database (EMDAT) and the Disaster Inventory System website (desinventar.net)] and concluded that these commonly used datasets immensely underestimate the burden of disasters on the PICs, particularly atoll nations [65]. He also compared the burden of disasters between PICs and the Caribbean islands to find that the burden of disasters is far more significant in the Pacific and also identified Tuvalu as the most exposed country in per capita terms. In per capita terms, the Pacific Islands face the highest disaster risk globally [65].

With increasing occurrences of cyclones in the Pacific region, Tuvalu has to strengthen DRM, response and coordination efforts and reduce disaster risk (e.g. prevention, preparedness and early warning systems). Here, we need to understand first the hazards and the exposure and vulnerability of people and assets to those hazards. Being able to identify exposure and vulnerability and quantify the current risks and potential impacts of hazards is crucial in making decisions for prevention.

## 6. Conclusion

The conceptual framework of disaster risk discussed is an essential stepping stone for more research, thus contributing to more knowledge about disaster risk and DRM in SIDS. Firstly, there is a need to examine the vulnerability and exposure of Tuvalu to climatic disasters at the household level. As such, using the available household data, geographic and topographic information are crucial in assessing exposure differentials between households. Here, we can also construct hardship profiles, hardship and exposure maps for households and islands to determine who are more likely to reside in highly exposed areas to disasters. With geo-coded locations linked to household surveys, we can employ spatial regression models.

Secondly, to truly examine the impact of disasters on Tuvalu, we need to conduct a household survey to quantify the impacts of a disaster following the conceptual framework of disaster risk and its associated components of hazard, exposure and vulnerability. We can also extend this conceptual framework to include responsiveness to disasters as an additional component of disaster risk. Through this, we can estimate loss and damage costs and construct

<sup>12</sup> Author's calculations based on the Tuvalu Census 2012 in [63]. For comparison purposes, [7] stated that Tuvalu is 'relatively highly densely populated at 437 people per sq km compared with an estimated 337 for India (1997), although Bangladesh one of the most densely populated countries in the planet has an estimated density of around 883 people per sq km'.

<sup>13</sup> See [63]. In absolute values, population on Funafuti in 1991, 2002 and 2012 were 3839, 4492 and 6194, respectively.

hypothetical policy scenarios for disaster risk reduction policies. Given the geographical settings of low-lying atoll islands, it is imperative to assess the impact of distant cyclones and its associated storm surge that often lead to flooding in the islands.

Last but not least, SIDS often face financial difficulties imposed by climate and disaster risks, especially for quick response and recovery. The fact that some SIDS do not have an insurance mechanism and often rely on aid for disasters stimulates our interest in developing a potential financial instrument for disaster risk management. Although there are other potential financial instruments, one option is to use their sovereign wealth funds (SWF) to contribute into a disaster fund that can then be used as a buffer for ex-post disaster risk management. We can quantify appropriate financial levels of support for expected disasters by calculating expected average annual loss (AAL). Moreover, we can assess the long-term sustainability of the SWF by forecasting its expected performance and therefore determine the feasibility of contributing to a disaster fund.

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