

2010). Climate change has been adversely affecting the vulnerability of developing economies. The various researches for exposure to vulnerability and reduction of impacts of climate change have been deeply analysed (Burton, 1993; Cannon, 1994; Cannon et al., 2003; Dercon, 2001, 2002, 2006; IPCC, 2007; Moser, 1998; Pelling, 2003; Barnett and Adger, 2007; McCarthy, 2001; Smit, 2003; Eakin and Luers, 2006; Bankoff et al., 2004; Füssel and Klein, 2006; Cutter, 2003; Ionescu et al., 2005; Kasperson et al., 2005). The vulnerability studies shed light on various social and economic factors affecting the societal setup in poor countries (Ibarrarán et al., 2010). The increased frequency of natural hazards due to climate change poses more vulnerability to less equipped countries (Downing, 1991). Therefore, it is crucial to understand the system by which climate change, and the implications of such system for current vulnerability to these climate changes. This enhanced understanding supports the scientific community and the policy makers for underlying the various causes of vulnerability, and provide policy for ameliorating such vulnerability (Adger, 1999).

15 IPCC explores vulnerability through three core concepts: firstly, “exposure magnitude” to which a system is physically in harm’s way; secondly, “sensitivity” of a system i.e. its likelihood to be affected by a shock; and thirdly, the “adaptive capacity” of a system to cope or adjust with the negative impacts of a shock (Barnett and Adger, 2007; McCarthy, 2001; Smit, 2003).

20 Social vulnerability is defined as the exposure of groups or individuals to stress as a result of social and environmental change, where stress refers to unexpected changes and disruption to livelihoods (Adger, 1999). This definition emphasizes the social dimensions of vulnerability following the tradition of analysis of vulnerability to hazards, food insecurity and as a dimension of entitlements. However, the predominant view is depending upon the physical dimensions of the vulnerability from the impacts of climate change. A system consisting of indicators is set up to analyse the relative vulnerability of given individuals or a societal setup (Adger, 1999).

25 A model of social vulnerability to reduce the impacts of climate change involves focus on the social aspects of such events. A model for vulnerability should be based

on human welfare aspects which leads to the environmental changes induced by the climate change gaining significance as and when they have cause and effect on the relative and absolute well-being of individuals and groups: according to O’Keefe and colleagues (1976), “without people, there is no disaster.”

5 A theory of vulnerability to climate change must also encompass the collective nature of vulnerability of a group or community to the impacts of climate change, involving a complex set of factors, including the institutional arrangements for preparedness for hazards. With greater numbers of social factors involved in collective vulnerability (gender, ethnic and other differentials of vulnerability (Blaikie et al., 1994), as well as the nature of different climate-related hazards, an exclusive focus on economic and material aspects of vulnerability has been argued to be misplaced. These diverse aspects determining vulnerability can be conceptualized as a set of entitlements: it is the structure or architecture of these entitlements that underpins both security and vulnerability (Adger and Kelly, 1998; UN/ISDR, 2004; Cardona, 2004; Wisner, 2002; Thywissen, 2006). These potential rights and reciprocal social coping mechanisms and informal social security are fluid and often only exactly determined in times of crisis (Platteau, 1991; Leach et al., 1997; Moser, 1998).

15 The vulnerability of a system is not only a matter of the number of indicators of the system or individuals in a population who are vulnerable through being exposed to stresses associated with environmental change or not having adaptive capacity. Thus, countries suffering higher losses of lives than others equally exposed have a higher relative vulnerability (Dille, 2005). By contrast, Venezuela, Afghanistan and Somalia are countries with a high relative vulnerability to floods (UNDP, 2004). According to Birkman (2007) the applicability of relative vulnerability measures worldwide is proved to be possible. There could be radical shifts in the classification of a country’s relative vulnerability due to the occurrence of one major disaster event without any changes in the underlying drivers of vulnerability.

2 Climate vulnerability in Samoa

Samoa is comprised of two large volcanic islands (Upolu and Savai'i) and several smaller islands with a total land area of approximately 2935 km². It lies in the southwest Pacific within an exclusive economic zone of 120 000 km² (GoS, 2013).

5 Samoa's islands are highly vulnerable to impacts from climate change, such as sea level rise, increased incidents of extreme events including flooding from storm surges, and tsunami inundation (SPCR, 2011). According to the World Bank, Samoa is ranked 30th of countries most exposed to three or more hazards. Samoa ranked 51st out of 10 179 countries in the Global Climate Risk Index 2012 report on countries that suffers most from extreme weather events (GoS, 2013). Samoa's climate is greatly influenced by the El Niño–Southern Oscillation (ENSO). The El Niño phase of ENSO generally brings dry conditions over the island group. In contrast, La Niña tends to bring wetter conditions. The influence of global warming on Samoa results in more frequent and 15 extreme rainfall events, longer dry spells, consistent drought events, hotter days, rising sea levels, extreme winds and extremely high air and water temperatures (Climate Risk Profile, 2007).

Samoa has suffered serious economic shocks caused by natural disasters. For example, there were severe cyclones in the successive seasons of 1989–1990 (i.e. Ofa) and 1990–1991 (i.e. Val), in addition to the major Cyclone Evan in 2012, which all 20 caused massive damage to infrastructure and other assets (World Bank, 2010). The cyclone killed at least five people and displaced 4763 people. Evan destroyed power plants, cutting power and disrupting communication services; it also destroyed buildings and roads, damaged vast swaths of crops and caused severe damage and nationwide disruption to water facilities and distribution systems. According to the Post 25 Disaster National Assessment (PDNA) (2013), “The total estimated damage and loss on Cyclone Evan are equivalent to about 28 percent of the total value of goods and services produced in the country in 2011”. The value of durable physical assets across all

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economic and social sectors destroyed by Evan (referred to as damage) is estimated at USD 103.3 million.

Infrastructure vulnerability to climate change is increasing around the world and Samoa is particularly vulnerable. The whole island population is highly vulnerable to 5 different hazards, but groups facing the highest risks are the rural poor in informal settlements, internally displaced people, and those living in marginal areas. Transportation, infrastructure, water, and tourism are sectors sensitive to climate extremes. The expected damage to infrastructure for selected climate change phenomena, for example high precipitation, cyclones and sea level rise, may result in coastal inundation, 10 flood damage to homes and property, and damage to roads, ports, bridges and other infrastructure. Samoa's National Adaptation Programme of Action (NAPA) identified nine sectors, which are highly vulnerable to the adverse impacts of climate change and climate variability, including extreme events. The nine sectors listed from highest to lowest vulnerability are water; agriculture and food security; forestry; health; urban settlements; coastal environments; communities; trade and industry; and works transport 15 and infrastructure.

The National Infrastructure Strategic Plan (NISP) outlines the government's priorities and strategic directions for major initiatives in the economic infrastructure sector over the next 5–10 years. In particular, the NISP is closely linked to the Strategy for the 20 Development of Samoa 2008–2012 (SDS). After any disaster, “building-back-better” is often advocated, but unless an appropriate assessment of future extreme events and climate-proof infrastructure is undertaken, the sustainability of that infrastructure remains at greater risk.

This paper is focused on the vulnerability of infrastructure to coastal hazards. Even 25 though the infrastructure framework involves many aspects, this paper focuses only on the water sector; that is, the physical components of the water sector infrastructure (e.g. buildings, embankments, bridges, water supplies and sanitation) and the “soft” components (i.e. early warning systems, community preparedness, etc.). The general

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concept of vulnerability can be analyzed in three main categories: physical, systemic and organizational/social.

This paper identifies vulnerabilities for key water-related infrastructures. A vulnerability assessment method has been adopted that need for assessing the climate-related vulnerability of four public infrastructure sectors of Samoan (i.e. water supply, sewerage, land transport, and power supply), provides an inventory of critical infrastructure for each sector, and ranks those infrastructure systems in terms of their relative vulnerability to climate-related hazards. The vulnerability assessment used the damage caused by the Cyclone Evan as a baseline proxy. Information on the damage to infrastructure was readily available from a study conducted by GoS (2013). Interviews were conducted with key stakeholders to identify ongoing initiatives, current gaps in the system, and possible adaptation options that could be carried out under the project.

3 Methodology

This section outlines the methods implemented to assess the vulnerability of public infrastructure systems and the well being of residents of Samoan to the hazards discussed in the previous section.

Recently the Sydney Environmental Vulnerability Assessment (SEVA) framework was developed (Tonmoy and El-Zein, 2013; Tonmoy et al., 2012) and applied to assess vulnerability to sea level rise (SLR) of public infrastructure systems of a local council (Shoalhaven City Council) in Sydney. It was developed specifically for assessing vulnerability of infrastructure systems and their users to SLR at a local scale, but can be used for any climate-related hazards. It is an approach where an indicator-based vulnerability model is developed in collaboration with the stakeholders. Involvement of local stakeholders is crucial in order to ensure that the exercise captures the most relevant local contexts. The main objective of this model is to rank a given set of infrastructure sector indicators based on their climate-related vulnerability. Once the model is developed the overall vulnerability index is developed by aggregation of indicators

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using one of the mathematical procedures discussed in the following sections. The following section describes the indicator-based vulnerability model developed for this study, its development process, and the mathematical approach used for aggregation of the developed model.

A participatory approach was used for the development of the vulnerability model, as it is essential to engage with local stakeholders to ensure that the most relevant local contexts are captured in the model. Two missions were conducted with the local stakeholders to identify needs and requirements. A detailed step-by-step process of the whole exercise is shown in Fig. 1.

The process flow diagram, shown in Fig. 1, demonstrates the process of assessing the vulnerabilities of infrastructure used in this paper. The assessment started with preliminary discussions with local experts regarding their organizational goal, objectives and existing methods used in the study. After reviewing previously conducted hazard studies of Samoan and other relevant literature, a conceptual model of the vulnerability of Samoa was developed. Following this conceptual model, a list of vulnerability indicators was proposed to the stakeholders for further consultation (1st phase of consultation), who then selected those that are most relevant in the context of Samoa. Starting from the IPCC definition of vulnerability, the Samoan Infrastructure Vulnerability Model (SIVM) was developed with a focus on the vulnerability of the infrastructure systems of Samoa to climate-related hazards by considering the biophysical, socio-economic and institutional dimension of risk.

In order to select the most relevant set of indicators for Samoa from the proposed set, the following stakeholders were identified and consulted in the first mission followed by a second mission; Planning and Urban Management Agency (PUMA) for water supply and sanitation; Land Transport Authority (LTA) for transportation and drainage; Electric Power Corporation (EPC) for power supply authority; Meteorological Department and Water Resources for early warning system for extreme climate events; Ministry of Works, Transport and Infrastructure for building back better and building codes. The details of the stakeholders interviewed are summarized in Table A1.

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Once the indicators of the model were finalized, the scores for each indicator of each infrastructure system were estimated in order to populate the vulnerability matrix. This was done in collaboration with the engineers and experts from the respective departments previously identified (2nd phase of the consultation). A 3rd phase of consultation may be required after development of this vulnerability index in order to discuss the results with the stakeholders and to identify whether it differs from their local perception of their vulnerability. The following sections describe the conceptual model as well as the indicators that were finally selected.

3.1 Conceptual model

One commonly used definition of vulnerability (illustrated in Fig. 2) was presented by the International Panel on Climate Change (IPCC) in its Third Assessment Report (IPCC, 2001), which was adopted for the Samoan context as well:

“[Vulnerability is] the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity” (McCarthy et al., 2001).

A general conceptual model of an infrastructure sector of the Samoan Islands followed from this and is shown in Fig. 3. Climatic events (e.g. storm surge, flooding and inundation, etc.) pose certain hazards in Samoa (referred to as “climate forcing”). The impact depends on the characteristics of the infrastructure (e.g. geographic location, physical integrity, etc.). The social, institutional and financial resources that the community has access to are considered as a reflection of its adaptive capacity.

For this vulnerability model, a given infrastructure system (e.g. water supply, transportation etc.) is taken as a socio-ecological system which needs to be ranked. A plausible cyclone with intensity equivalent to Cyclone Evan is considered as the hazard. The physical integrity of the public infrastructure of a given sector and the well-being

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of its users were considered as the valued attribute of concern. The vulnerability of the users of a given infrastructure is partly determined by the extent to which the service it provides is critical, and the ability of the service providing authority and/or the users to deploy an alternative to the disrupted service. The overall infrastructure vulnerability of the IS was determined by the physical impact on its infrastructure and the sensitivity of its users to the impacts, minus the capacity of the authority and individuals to cope with those impacts.

3.2 Selecting indicators

Following the definition of the model parameters, indicators were identified through which SIVM could be made operational, i.e. used as a basis for ranking vulnerabilities of the infrastructure system. The selection was conducted in collaboration with government experts from Samoa.

First, “reported damage of the infrastructure during Cyclone Evan” is taken as an indicator of physical exposure of the infrastructure to a climatic hazard (V1). Second, the sensitivity of users of a given infrastructure was captured by expert and stakeholder judgment about the degree to which the disrupted service is critical, i.e. the extent to which it serves a vital function (e.g. from the user’s point of view the water supply may be more vital than sanitation) (V2). Finally, adaptive capacity in this case is reflected by the capacity of the local authority to repair the infrastructure after a possible disruption (V3). The vulnerability indicators of SIVM and scales used for eliciting experts’ and stakeholders’ judgment for V2 and V3 are shown in Tables 1–3.

The infrastructure systems of Samoa were divided into two categories: hard infrastructure, consisting of water supply, sewerage, land transport infrastructure and power supply infrastructure; and soft infrastructure, consisting of early warning systems and knowledge development programs. Only hard infrastructure components were considered in this study.

Any design of infrastructure related to the hydrologic cycle (e.g. levees, embankments, bridge, roads, etc.) is based on an underlying assumption that the probability

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Considering the above rationale, we emphasize the need to strengthen Samoa's water supply sector, particularly with reference to the Integrated Water Management Plan (IWMP) for the five catchments in the Apia area. Adaptation should not be understood as simply implementing the correct technology or practice. It should be part of a coherent, inter-sectorial strategy to reduce climate risk and maintain sustainable water resources. IWMP is a strategy being recommended here that provides an overall decision-making framework for climate change adaptation in water resources through mainstreaming climate adaptation into its plans. To address the issue of climate risks, the IWMP would need to include a vulnerability and adaptation assessment. An adapted IWMP will enable the Government of Samoa to strengthen the overall water management plan by considering future climate risk and "ridge-to-reef" approaches being suggested by regional projects to be implemented in the design of water management plans.

The results suggest only the relative vulnerability of the four infrastructure systems of Samoa, not the vulnerability of each individual infrastructure component due to lack of database. Thereafter many other factors hinder the vulnerability assessment such as the study was designed and implemented using information collected from existing reports; therefore the quality of results of this study is highly dependent on the quality of those reports. Damage to infrastructure was modeled using the reported damage data of Cyclone Evan. An ideal vulnerability study would require a physical hazard mapping of areas under investigation of such a coastal flooding event. However, such a detailed assessment of physical climate risk for Samoa was neither readily available nor within the scope of this report. Therefore, this study adopted the damage caused by Cyclone Evan as a proxy for such investigative work. It can be argued that the use of actual damage data instead of a model-based risk assessment data can provide a more realistic approach to the problem. An indicator-based model was used for the vulnerability assessment. Indicators were selected in collaboration with stakeholders in order to make sure that they are relevant for the local context. However, there is a possibility that the study might have missed some other relevant key processes.

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6 Conclusions

This paper studied the existing available data and reports to assess climate-related vulnerability of four major infrastructure sectors on Samoa. An indicator-based vulnerability model, SIVM, was developed for this purpose. A range of stakeholders was consulted both at the model development and data collection stages. The study identified some of the critical infrastructure components of each sector and collected data on the vulnerability indicators for each of the sectors. The resulting vulnerability index suggests that the transportation sector is the most vulnerable among the four sectors considered in this study. High physical exposure and comparatively lower capacity to repair the transport infrastructure, such as bridges, accounted for the high vulnerability. The power sector of Samoa was ranked as the second-most vulnerable sector, mainly because of the high physical exposure of the power generation and distribution system. The water supply sector was ranked third. Some of the water supply infrastructures, such as the Alaoa, Tafitoala and Tiavi water treatment plants, were rated as very critical infrastructure; they play a key role in maintaining safe water supply for public use. The sewerage system was ranked the least vulnerable sector. The sewerage system of Samoa is mainly composed of individual household latrines, which are comparatively easy to repair locally. Based on the results of this vulnerability assessment, a list of adaptation options and their possible outcomes were developed through consultation of Government of Samoa. Therefore, considering the current gaps and vulnerabilities of key infrastructure, this report proposes developing a "ridge-to-reef" integrated watershed management plans for the greater Apia area.

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Table 3. Scales used for all V3 for infrastructure system.

Description	Scale
Full capacity to repair	3
Partial capacity to repair	2
Cannot repair with existing capacity	1

Table 4. Infrastructure needs assessment by stakeholders.

Infrastructure	Needs Assessment
Housing and land use	<ul style="list-style-type: none"> - Flood hazard zoning and construction of new houses in the safe area - Demonstration of building back better with climate proof housing
Land transport	<ul style="list-style-type: none"> - Improvement of storm water drainage system to reduce flooding behind roads - Construction and retrofitting of damaged bridges - Construction of roads
Water	<ul style="list-style-type: none"> - Development of flood forecasting system for Vaisigano river basin and other river basin as well. - End-to-end early warning mechanism for flood events - Rainwater harvesting at family and community levels - Routing the drainage system far from the water source and supply systems and other essential, sensitive infrastructures. - Sensitization to community people about the efficient use of water
Sanitation and water supply	<ul style="list-style-type: none"> - Support sanitation service to rural populations - Promotion of drinking water treatment system at household level as the point of use (POU) options - Education and awareness program about the diarrheal and other water borne diseases
Electricity	<ul style="list-style-type: none"> - The electricity networks can be passed through underground system so that the overtopping of sea water does not affect - Relocation of main supply system from the coastal hazard zones - Detail assessment of the risk of hydro-power stations and rebuild climate proof supply network

Table 6. Vulnerability matrix for the 4-infrastructure system considered in this study.

Infrastructure system	Indicator values for the whole system		
	V1 – aggregated damage for all infrastructure component of the system	V2 – average criticality of the infrastructure component of the system	V3 – average repair capacity of the infrastructure component of the system
Water Supply	3 708 415	2.2	2
Sewerage	4 329 474	3.0	1.0
Power Supply	16 793 640	1.62	1.46
Land Transportation	25 987 982	1.25	1.50

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Table 7. Vulnerability indices.

Infrastructure system	Normalized indicators			Index	Rank
	V1	V2	V3		
Water Supply	–	54.3	65	119.3	3rd
Sewerage	2.8	100	–	102.8	4th
Power Supply	58.7	20.9	100	179.6	2nd
Land Transportation	100	–	97.5	197.5	1st

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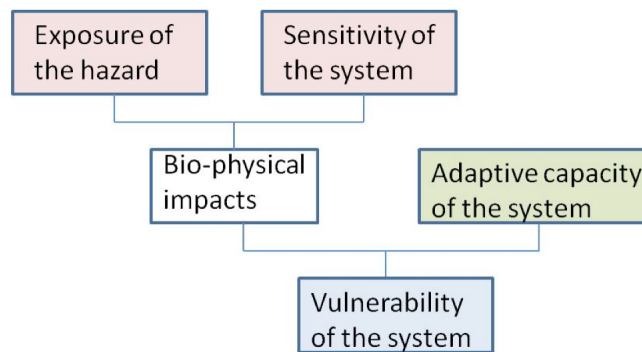


Figure 2. Components of vulnerability (adopted from IPCC, 2001).

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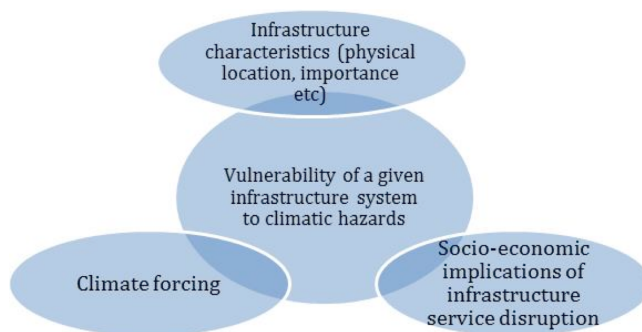


Figure 3. Vulnerability model.

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