Developing climate resilient WaSH in the Pacific

Adaptation Decision Making Framework from the DFAT-funded PACCWASH Project

Wade L. Hadwen (Griffith University), Morgan C. MacDonald (Griffith University), Annika Kearton (International WaterCentre), Mark Elliott (University of Alabama), Terence Chan (Monash University), Kate Shields (University of North Carolina)

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Executive Summary

Climate change is a serious threat to Pacific Island Countries (PICs) and their freshwater resources. Sea level rise, saltwater intrusion, increasing evaporation rates and changing patterns of rainfall and extreme events (such as floods, cyclones and droughts) will all affect the water cycle and, potentially, the availability and quality of water for human use. This poses significant adaptation challenges for sustainable development and human health in PICs, especially with respect to water, sanitation and hygiene (WaSH) infrastructure and practices. Indeed, throughout the Pacific region, there is acceptance that taken as a whole, PICs have underperformed in WaSH over the MDG period and efforts to improve the situation are confounded by specific context and adverse impacts of climate events.

This Australian Government Department of Foreign Affairs and Trade (DFAT) funded project - *Pacific Adaptation to Climate Change for Water, Sanitation and Hygiene (PACCWASH)* - was developed to incorporate climate change impacts into adaptation decision-making for management of WaSH in remote and rural communities, with case studies at two ends of the regional climate spectrum: flood-prone catchments in the Solomon Islands and drought-prone atolls in the Republic of the Marshall Islands. The PACCWASH project adopted a systems approach to understanding WaSH and climate change threats in rural communities in PICs. This is particularly important in climate-vulnerable remote and rural communities, as the link between climate impacts, water systems, sanitation practices and hygiene behaviour can be used to highlight how particular practices or interventions can lead to negative outcomes. Indeed, a systems approach can show how poor sanitation and faecal waste management practices can also represent a major risk to water supply, and, by extension, to human health.

One of the greatest challenges in terms of understanding WaSH needs and priorities in remote and rural communities is the lack of data and capacity to process what data is available. With this in mind, we developed an approach that married together participatory (focus group discussion) and survey tool methodologies to generate deep and thorough understanding of the 13 communities – five in the Solomon Islands (SI) and eight in the Republic of the Marshall Islands (RMI) - we visited for detailed analysis. We digitised long and complicated surveys to develop a tablet-based methodology for assessing household (HH) level water, sanitation and hygiene practices, which improved data quality, reduced errors and reduced the length of time for each survey to be completed. This new tool offers great promise to government and non-government agencies wishing to develop a deeper understanding of WaSH complexity in remote and rural communities in the Pacific region and beyond. Indeed, it is very clear from our research that regular use of multiple water sources is commonplace in almost all households – this is important both as a feature of the adaptive capacity of remote communities but also in the context of monitoring and evaluation approaches with respect to WaSH, which focus exclusively on a 'primary water source'. Our data show that this approach is misleading and dangerous in the Pacific region and that a broader, systems-based analysis of water sources, uses and seasonal changes, is required to fully appreciate both the current WaSH systems and where the opportunities lie to develop climate resilient practices.

In addition to the knowledge gained through our digitised survey, we also gathered anecdotal local knowledge sourced from separate women's and men's focus groups held in each community. This was to inform our understanding of the WaSH settings and to understand the impacts of extreme climatic events through the eyes of the local people. Capturing knowledge and personal accounts of the impact and response to extreme events in each community unearthed a rich pool of knowledge and adaptive capacity within remote, rural communities. Not only did this enable us to use that knowledge in the development of our decision support tool, but it also showed how traditional and contemporary knowledge and technologies can together support the development of climate resilient WaSH systems in the Pacific. We were also able to learn a lot about interventions and development activities through the focus group sessions. Indeed, in terms of interventions in rural communities that focus on water systems, we learnt that there is a limited number of interventions/adaptations to WaSH (technologies and approaches) used in PICs – and to variable levels of success – and these are conditioned by culture and environment. Many externally driven adaptations are hardware focused and capacity building for operation and maintenance is a frequent cause of failure.

Along with recognition of the use of multiple water sources in all households comes the recognition that traditional measures and materials are still used in PICs and many of these approaches contribute to climate resilience. Rainwater is typically viewed as a high quality water source and yet there is substantial difference in the collection and management of this water source among communities in SI and RMI. In SI, rainwater collection is haphazard and not well managed, whereas sharing of individual HH water resources in RMI is a major contribution to community wide resilience to drought. A deep understanding of household and community level interventions and their management is required to determine what interventions might hold the most promise with the greatest opportunity for uptake and optimization across these diverse social, cultural, economic and environmental settings.

From a sanitation perspective, it is clear that sanitation practices are many and varied across the communities assessed. Open defecation (OD) is still widespread throughout the region, although the practice is highly managed and culturally reinforced in some communities and not at all in others. Within the context of our systems approach to evaluating WaSH and climate change, it is also clear that some widespread sanitation technologies are highly likely to contaminate water sources, increase the level of risk to human health and decrease overall community resilience.

In order to develop a systems understanding of WaSH in remote Pacific communities, we used the data collected through the surveys and focus group discussions to build two Bayesian Belief Network (BBN) models, one for flood-prone communities like those visited in the Solomon Islands, and one for the drought-prone atoll communities like those visited in the Republic of the Marshall Islands. These models use an integrated system network which captures all aspects of WaSH systems, including seasonal changes in water source quality and quantity, changes in household behaviour and WaSH related responses to extreme climate events. Critically, the BBN models capture the local view of WaSH and can then be used to identify and compare adaptation options in response to a wide range of climate change threats. In terms of scenario testing, the BBNs can help us visualise the effects of different climate impacts and, in turn, evaluate the likely outcomes and efficacy of different adaptation options. The need to evaluate options prior to implementation is highlighted by the fact that current decision making is informed by incomplete or outdated information and this can have significant negative downstream effects including maladaptation (causing additional problems), inappropriate spending and misallocation of resources and lack of community acceptance and maintenance of the delivered services. Finally, the BBNs offer great capacity for analyses at multiple scales - they can be applied at either the community scale (for specific community conditions and adaptation options) or the regional, provincial or country scale, where they can be used to compare scenario options to inform country level strategy and planning.

Our policy analysis revealed that there are certainly policy, programming and technical challenges to integrating WaSH and climate change in PICs. Many of the country-level policies on water and sanitation and water-based adaptation, disaster reduction and emergency response are disconnected and insufficiently specific to guide effective action. There are also many actors involved in development WaSH /climate change adaptation/emergency WaSH and community and there are also a variety of formal and informal systems. Coordination and cooperation are poor, leading to ineffectiveness and inefficiencies. Despite these challenges, there are technical, programmatic and policy opportunities to substantively improve WaSH development, preparedness and emergency response in the face of climate change threats.

The major findings of the PACCWASH project will help communities, regional authorities, PIC governments, aid agencies and non-government organisations to understand, plan and prioritise the implementation of climate-resilient WaSH services and infrastructure in rural remote communities throughout the Pacific region. Ultimately, our research indicates that we can fuel sustainable development through understanding and mitigating the impacts of climate-related disasters by combining traditional and contemporary knowledge to deliver effective technologies, approaches and strategies for climate resilient WaSH in PICs.

The five key principles stemming from the PACCWASH project for developing climate-resilient WaSH in the Pacific are as follows:

1. **Adopt a systems approach**: Adopt an integrated systems approach to incorporate all dimensions of climate change and all of the connected aspects critical to developing sustainable water, sanitation and hygiene systems. A systems approach can enable decision makers to assess a) climate change impacts, b) current WaSH systems and their vulnerabilities, c) climatic and non-climatic aspects concurrently, d) intervention performance and unintended consequences (maladaptation) and e) the relative benefits of combined interventions, including software (e.g. maintenance) and hardware (e.g. rainwater tanks) approaches. This integrated and deliberately systematic approach to climate resilient WaSH also inherently includes the need to involve stakeholders from across sectors and have them provide the best available data to inform decision making.

2. **Use models and new tools to collect and analyse data**: To enable the implementation of risk management for the protection of water resources and provision of sustainable WaSH services, a framework and clear guidance on methods and tools for data collection, risk assessments, analyses and management is required. The use of models and digital technologies to support data collection, analysis and decision making opens up great opportunities in regions like the Pacific. New tools, including the BBNs and the CAPI tablet-based survey developed and implemented in the PACCWASH project are excellent examples of computer-based tools that can simplify complex tasks and provide managers and policy makers with increased capacity to make decisions in a systematic way. As outlined in point #1 above, a BBN model offers the capacity both to integrate diverse sources of data as well as

to capture the connectivity within systems to ensure that decisions around particular climate change scenarios or intervention options can be made with reference to both the anticipated and unintended consequences on the system in question.

3. **Learn from regional activities**: There is a lot of work underway in the Pacific region, both on WaSH development and, increasingly, on climate change threats and adaptation options, so there is a growing opportunity to learn from the successes and failures of projects and policies implemented throughout the region. Coupled with a systems-understanding through the use of a BBN model (points #1 and #2 above), regional sharing will enable policy makers to make strong decisions whilst keeping in mind the local social, cultural, economic and environmental context of rural and remote PIC communities.

4. **Develop integrated governance structures**: To foster greater cooperation and coordination at the project and policy scales, opportunities exist for improved governance structures which will mainstream and drive climate change adaptation and disaster risk reduction activities across WaSH and other sectors. Specifically, Rural WaSH policies and plans should clearly define functions and responsibilities for reducing and managing climate and disaster risks at the national government, provincial government and community levels. This should include coordination between WaSH stakeholders and disaster management groups, in order to strengthen links between disaster and development WaSH, and align with existing institutional structures for disaster risk reduction and management.

5. **Build capacity and understanding**: Efforts to build capacity and understanding of the complexity of WaSH and climate change impacts are required throughout the Pacific region, as this will enhance adaptive capacity to climate variability and change. Targeted training to build capacity for risk management is necessary at all levels of government, down to the community. Joint capacity building exercises with climate change adaptation (CCA) and disaster risk management (DRM) actors could also improve cross-sectoral partnership and coordination.

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Acronyms and Abbreviations

BBN – Bayesian Belief Network

CAPI – computer-assisted personal interviewing

CC – Climate Change

CCA – Climate Change Adaptation

DRR – Disaster Risk Reduction

HH - Household

MDGs – Millennium Development Goals

NGO – Non-Government Organisation

OD – open defecation

PAPI – Paper assisted personal interviewing

PCA – Paris Climate Agreement

PICs – Pacific Island Countries

RO – Reverse Osmosis

RWH – rainwater harvesting

RWT – rainwater tank

SDGs – Sustainable Development Goals

WaSH – water, sanitation and hygiene

Watsan- water and sanitation

Section 1: Understanding WaSH and climate change in the Pacific

The delivery of water, sanitation and hygiene (WaSH) services represents a significant challenge in many developing countries, including those in the Pacific (WHO 2013). Although water and sanitation coverage is increasing in many regions around the globe, overall conditions remain poor and many Pacific Island Countries (PICs) fell well short of reaching their Millennium Development Goals (MDGs) in 2015 (WHO 2013). Whilst there is great diversity within the fifteen PICs, six of these are rated as Least Developed Countries according to the United Nations (UN 2014). The isolated geography of PICs, combined with small and predominantly rural populations, limited resources and diverse cultures make the provision of WaSH services challenging. PICs can also be typified as having costly access to markets and supply chains (affecting investment in WaSH infrastructure and maintenance) as well as limited human and technical resources (Briguglio 1995).

For more than 20 years now the WaSH challenges already faced by communities within the Pacific have been intensified by climate change impacts (Meehl 1996; Mimura et al. 2006). Indeed, in 2013, a report from the WHO Regional Office for the Western Pacific stated that "…WaSH statistics, associated with a less than optimum management of water resources may aggravate the gloomy perspectives brought about by climate change, which appears to be exacerbated in the Pacific islands. Drinking-water and sanitation relies on water governance and water resources management and this is closely linked with climate change in the Pacific islands" (WHO Regional Office for the Western Pacific 2013). This tight relationship between water availability (and accessibility), water quality, sanitation and hygiene underpins the need for WaSH interventions and continued investment in Pacific communities (Meehl 1996). In addition to non-climatic pressures, the long term pressures from climate change further threaten the sustainability of water and sanitation services in many vulnerable PIC communities (Meehl 1996; Mimura et al. 2007). This is not just through incremental changes in climate that have been projected, but also through extreme events such as floods, cyclones and droughts associated with climate change which can render safe communities more vulnerable to WaSH related problems during extreme events (White & Falkland 2010).

To better incorporate issues of water security, water quality and climate change into WaSH activities, there is a case for a broadening of the focus of WaSH to encompass a 'whole of catchment' and more integrated understanding of the water cycle. This case has been supported through the development of a much broader and integrated water-focused goal (Goal 6) of the Sustainable Development Goals (SDGs), which seeks to bring together all aspects of water resource management and delivery of WaSH services, both in developed and developing countries (UN 2015). Critically, the understanding inherent in Goal 6, reflects the fact that there may be a number of places within the water cycle where interventions can improve the availability and quality of water resources and these interventions may in turn reduce risks within WaSH systems. For example, if actions are taken to protect water quality, possibly through riparian restoration and improved land management practices (Dosskey et al. 2010), the health risks associated with poor water quality can be reduced (Jagals et al. 1997). Furthermore, by adopting a more holistic and systematic approach to WaSH, services may be designed and delivered in a way that builds resilience in communities, potentially buffering them from some of the impacts of climate change and associated extreme events like droughts and floods (Hadwen et al. 2012).

A review of WaSH in the Pacific

Drinking water and sanitation coverage in most PICs falls short of global averages. The MDG target of halving the proportion of the global population without access to improved drinking water was met in 2010 (WHO & UNICEF 2014). While sanitation will miss the global MDG target, nearly two billion people gained access from 1990-2013; additionally, a target that also included access to shared sanitation facilities would have been met in 2014 (Cumming et al., 2014). While this global progress is a major achievement, it is not consistent for all regions. Critically, the MDG region of Oceania, which includes 15 PICs, lags behind in drinking water and sanitation access (Table 1.1).

The 2012 Joint Monitoring Programme (JMP) data on drinking water and sanitation coverage illustrate the deficit between the Oceania region and the rest of the world. Oceania has the lowest proportion of population (56%) with improved drinking water, lower than Sub-Saharan Africa and South Asia, with over 30% relying on raw surface water. The 2012 sanitation data are also dire, with only 35% using improved facilities and 12% practicing open defecation (WHO & UNICEF 2014). Progress in sanitation has been stagnant in Oceania with the percent using improved facilities declining slightly between 1990 and 2012, in stark contrast to the progress made in all other MDG regions (Figure 1.1). The reality may be even worse than reported; key local stakeholders have expressed concern that JMP estimates of sanitation coverage for Oceania seem "exceedingly optimistic" (WHO & SOPAC 2009).

Table 1.1 Percent improved water and sanitation coverage in Pacific Island Countries (data from the WHO & UNICEF Joint Monitoring Program - JMP 2014). ND signifies situations where there are no, or insufficient, data.

Country	Population (x1000)	% Water coverage (total improved)		% Sanitation coverage (total improved)	
		Urban	Rural	Urban	Rural
American Samoa	70.7	100.0	100.0	62.5	62.5
Cook Islands	20.5	99.9	99.9	97.2	97.2
Fiji	874.7	100.0	92.2	92.1	81.7
French Polynesia	273.8	100.0	100.0	97.1	97.1
Guam	162.8	99.5	99.5	89.8	89.8
Kiribati	100.8	87.4	50.6	51.2	30.6
Marshall Islands	55.7	93.4	97.5	84.2	55.5
Micronesia (Fed. States of)	103.4	94.8	87.4	85.1	49.0
Nauru	10.4	96.3	ND	65.6	ND
New Caledonia	253.2	98.5	98.5	100.0	100.0
Niue	1.4	98.5	98.6	100.0	100.0
Northern Mariana Islands	62.2	97.5	97.5	79.7	79.7
Palau	20.8	97.0	ND	100.0	100.0
Papua New Guinea*	7167.0	88.0	32.8	56.4	13.3
Samoa	188.9	97.4	98.8	93.3	91.1
Solomon Islands	549.6	93.2	77.2	81.4	15.0
Tokelau	1.1	ND	97.4	ND	92.9
Tonga	104.9	99.0	99.4	99.4	88.9
Tuvalu	9.9	98.3	97.0	86.3	80.2
Vanuatu	247.3	97.8	88.3	65.1	55.4
Total	10279.0	94.3	44.5	75.7	23.6

* The comparatively large population of Papua New Guinea has a strong influence on the statistics of total water and sanitation coverage for the region.

Whilst regional averages provide insight into the need for drinking water and sanitation progress, they also mask the differences between and within PICs (Table 1.1). Regional averages are strongly influenced by coverage in Papua New Guinea (PNG), which represents approximately 70% of the population of the Oceania MDG region.

The proportion of investment of overseas development aid (ODA) into water and sanitation in Oceania is high (>10%), but the amount spent per capita is relatively low - one of only three MDG regions with spending in water and sanitation below USD100 per capita over 2000-2010 (Bain et al. 2013). Particular challenges in the Pacific include a high reliance on community rather than household connections for water, especially in countries that are still predominantly rural.

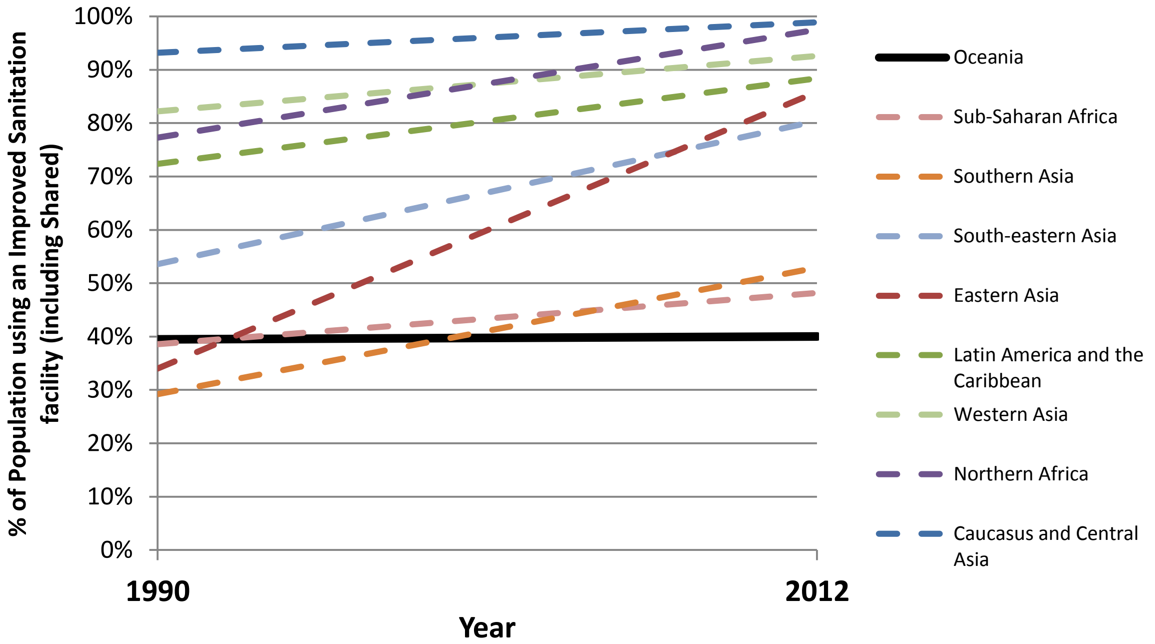

Figure 1.1 Percent of population using an improved sanitation facility (including shared facilities) by MDG region, 1990-2012. Data from: WHO & UNICEF 2014.

During the MDG period a 'surprise' of increasing access was household connections, an increase that did not translate to the Pacific context (Bain et al. 2013). This is partly due to the challenging complexity of freshwater resources throughout the Pacific and the limited human and financial capacity of many countries. Commonly, small rural communities are too remote and, therefore, too expensive to equip with improved water and sanitation, whilst urban centres struggle to deliver the same services because infrastructure consistently lags behind urban expansion (Poustie & Deletic, 2014). Despite regional efforts and frameworks for action (SOPAC & ADB 2003), there remains a lack of planning specifically directed to advance communities towards global water and sanitation goals (WHO & SOPAC 2009). One particular challenge is the poor absorptive capacity of governments in the Pacific to build, operate and maintain, and provide supportive enabling environments and many (for example, the Solomon Islands) provide examples where the disbursements of ODA funding cannot keep up with ODA commitments. Additionally, many of these states are vulnerable – not only to climate change impacts, but also to unstable political environments (particularly in Melanesia where cultural won tok allegiances are often stronger than nation allegiances) and conflict (WHO & SOPAC 2009).

Climate change threats in the Pacific region

Due to their limited size, geology and topography, freshwater resources on small islands are extremely vulnerable to changes in climate and rainfall (Mimura et al. 2007; Hanna 2013). Multi-model global climate projections point to increases in global average water vapour, evaporation and precipitation over the 21st century (IPCC 2013a; Kirtman et al. 2013). The outputs also suggest that precipitation will generally increase in the areas of regional tropical precipitation maxima, including the tropical/equatorial Pacific in particular, where increases in annual precipitation may exceed 20% (IPCC 2013a; Perkins et al. 2012). Heavy precipitation events are very likely to become more frequent, and the intensity of these events is projected to increase, particularly in the tropics (IPCC 2013a, 2013b). A range of models also indicate tropical cyclones will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases in tropical sea surface temperatures (IPCC 2013b). With the caveat of a large uncertainty in projections for this region, the ensemble projections for the group of South Pacific nations including the Cook Islands, the Solomon Islands and Tuvalu, are that average rainfall during the wet season is projected to increase; while for Vanuatu, Tonga, Samoa, Niue, Fiji, this increased rainfall during the wet season is accompanied by a decrease in dry season rainfall (Christensen et al. 2013).

Immediate/direct climate change impacts on water resources can occur via: (1) precipitation (Meehl 1997; Perkins et al. 2012); (2) the resultant intense runoff (Samaniego & Bardossy 2006; Arnell et al. 2011) and flash flooding leading to the temporary contamination of drinking water supplies impacting on water quality; (3) the safety of groundwater, including slower recharge as well as saline intrusion from reduced freshwater flow (Roy & Connell 1991; Chui & Terry 2013); and (4) changes in seasonality/timing of precipitation (Meehl 1996; Irving et al. 2011). Impacts on atolls may be particularly severe, e.g. a 10% reduction in average rainfall (by 2050) would lead to a 20% reduction in the size of the freshwater lens on Tarawa Atoll, Kiribati (Mimura et al. 2007).

Indirect impacts of climate change on water resources are likely to occur due to: (1) pressure on ecosystems and biodiversity and subsequent changes, e.g. changes in favoured forest/tree species, desertification (Amadore et al. 1996); (2) demographic changes as populations are displaced, including the resultant increase in urbanisation; (3) changes to agro-ecosystems and implications for food security (World Bank 2000; Hanna 2013); (4) potential for contamination of water resources as changes/pressures occur, e.g. changes to runoff and sedimentation under changed precipitation intensity, frequency and locations; changing sanitation patterns/practice and public health with demographic and temperature change (Singh et al. 2001; Miller et al. 2013); and (5) sea level rise (WHO & SOPAC, 2009).

The global mean sea level is projected to rise by 40 to 63 centimetres by the year 2100, mainly due to thermal expansion of the ocean (IPCC 2013a), with some estimates of up to an 88 centimetre sea level rise in the Pacific island countries by 2100 (Miller et al. 2013). Sea level rise is predicted to have significant impacts in four main areas: (1) coastal wetland change (Ellison 2009); (2) increased coastal flooding (Pittock et al. 1996); (3) increased coastal erosion (Leatherman 1996); and (4) saltwater intrusion into estuaries, deltas and groundwater (McLeod et al. 2010; Chui & Terry 2013; Morgan & Werner 2014). Reduction in the size of individual islands as a result of sea level rise is likely to reduce the size of the freshwater lens on atolls by as much as 29% (World Bank 2000), above and beyond any changes in recharge rates due to changes in precipitation.

A review of published knowledge around WaSH in the Pacific

An examination of the peer-reviewed and published knowledge of WaSH in the Pacific was conducted both to assess knowledge gaps and to inform future investment in research both across PICs and thematic areas relevant to WaSH development. This review included three online databases of peer-reviewed journals for articles published in English, including Web of Science, IWA Publishing and Pub Med. The search had no date restrictions, and all searches were conducted between September 2014 and February 2015. Three categories of geography, WaSH and health, formed 912 unique search term combinations for each of the three databases.

To understand the state of peer-reviewed knowledge of WaSH research in the context of a broad water resource management lens to capture the impacts of WaSH on the environment and *vice versa,* as well as the reported impacts of different methods of governance on WaSH service delivery and resource management. The aim of this review is to inform the next generation of WaSH research in the Pacific, while highlighting the need for a systems approach like integrated water resource management (IWRM) to improve access to 'safely managed' drinking water and sanitation (Hadwen et al 2015; UNICEF 2015 – WatSan outlook in PICs). Furthermore, a thorough analysis of the state of knowledge around WaSH, within the specific socioeconomic, cultural and environmental context of the PICs is needed to gain an appreciation of the degree to which progress and improvements in WaSH services might be either currently limited by, or potentially enhanced by, our understanding of the systems and the local contexts of the communities in need of WaSH service provision.

A total of 3,979 papers were identified across the three online databases, and 3,268 of these were eliminated on the basis of title and keywords. Of the remaining 711 studies, 205 were considered eligible for full text screening. Full text could not be found for 36 of these records, and an additional 84 papers were omitted because they did not satisfy the inclusion criteria.

Between 1955, the year McCarthy et al. published a study on sanitation and intestinal parasites in Western Samoa, and 1975 there were only five peer-reviewed publications involving WaSH in PICs. Nineteen studies were published between 1975 and 1990, for an average of five studies every four years, a rate which more than doubled between 1990 and 2000. This rate, again, more than doubled with an average of over six publications per year, for a total of 103 peer-reviewed studies published between 2000 and 2015. It is difficult to determine precisely what caused these surges in scientific effort and publication output, but the increases observed in 1990 and again in 2000 coincide with the UN Summit for Children and the adoption of the UN Millennium Declaration (later known as the Millennium Development Goals), respectively. Studies on public health and the environment are most numerous, with the number of management and governance studies increasing at a more rapid rate, as seen in Figure 1.2. There are also some emergent trends in the spatial distribution of WaSH research publications, with over 42% of all peer-reviewed WaSH research occurring in PNG, Fiji and Kiribati (Figure 1.3). Conversely, there were no peer-reviewed research articles for the Marianna Islands, Niue or Tokelau.

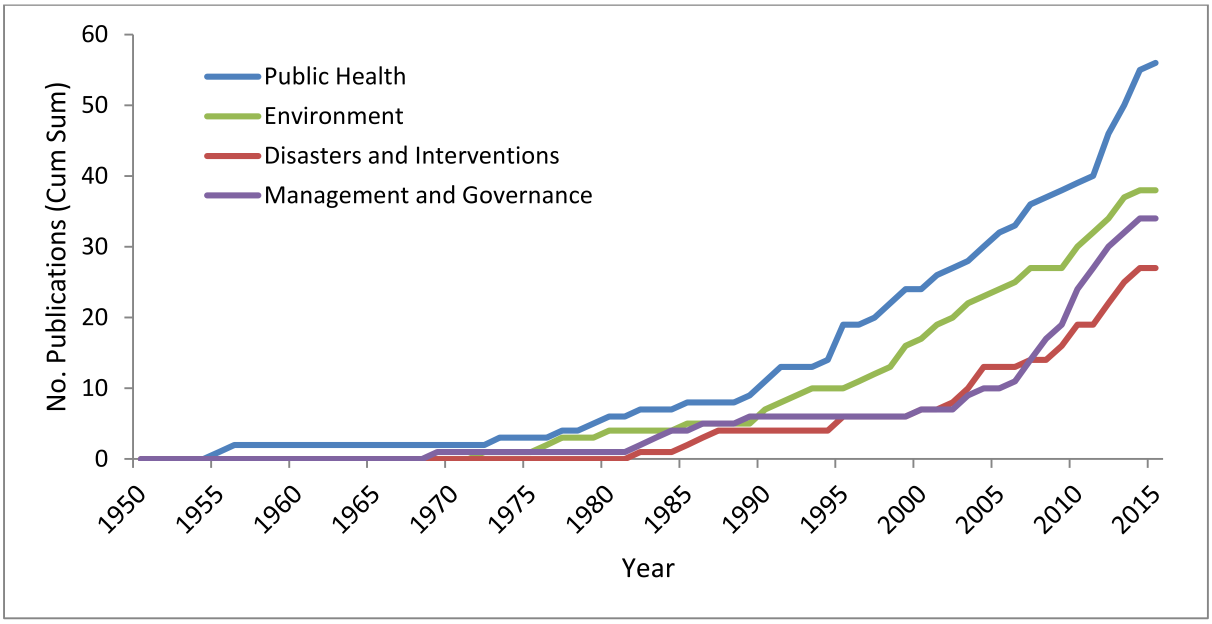

Figure 1.2. Chronological representation of PIC WaSH publications by theme areas discussed in this review.

Aside from a general paucity of scientific studies on WaSH in PICs, the peer-reviewed literature does a good job of implicitly characterizing some of the extreme challenges associated with WaSH service delivery in the region. There is a strong understanding of how droughts and water shortages impact the freshwater lenses of low-lying coral atolls (Ghassemi et al. 1990; Griggs & Peterson, 1993; Koda et al., 2013), as well as some understanding of the potentially worsening conditions caused by climate change (Rapaport, 1990; Roy & Connell, 1991; White et al., 2007). We also know that without enough water for handwashing and personal hygiene the risk of contracting a potentially fatal enteric pathogen is much higher (Bukenya and Nwokolo 1990, Greenwell et al. 2013,), and that animal husbandry practices significantly increase this risk (Berlioz-Arthaud et al. 2007, Guerrier et al. 2013, Thompson et al. 2014). WaSH interventions are intended to curb this risk using different mechanisms and stop-gap strategies to isolate pathogens from food and drinking water, but the majority have thus far been unsuccessful or unsustainable (Wohlfahrt and Kukyuwa 1982; Clark et al 2014). Lastly, a shortage of both human and financial resources, along with uncoordinated planning and implementation from different levels of local government have been cited as reasons for failed attempts at the implementation of WaSH policy and legislation (Keen, 2003; van der Velde et al., 2006; South et al., 2004).

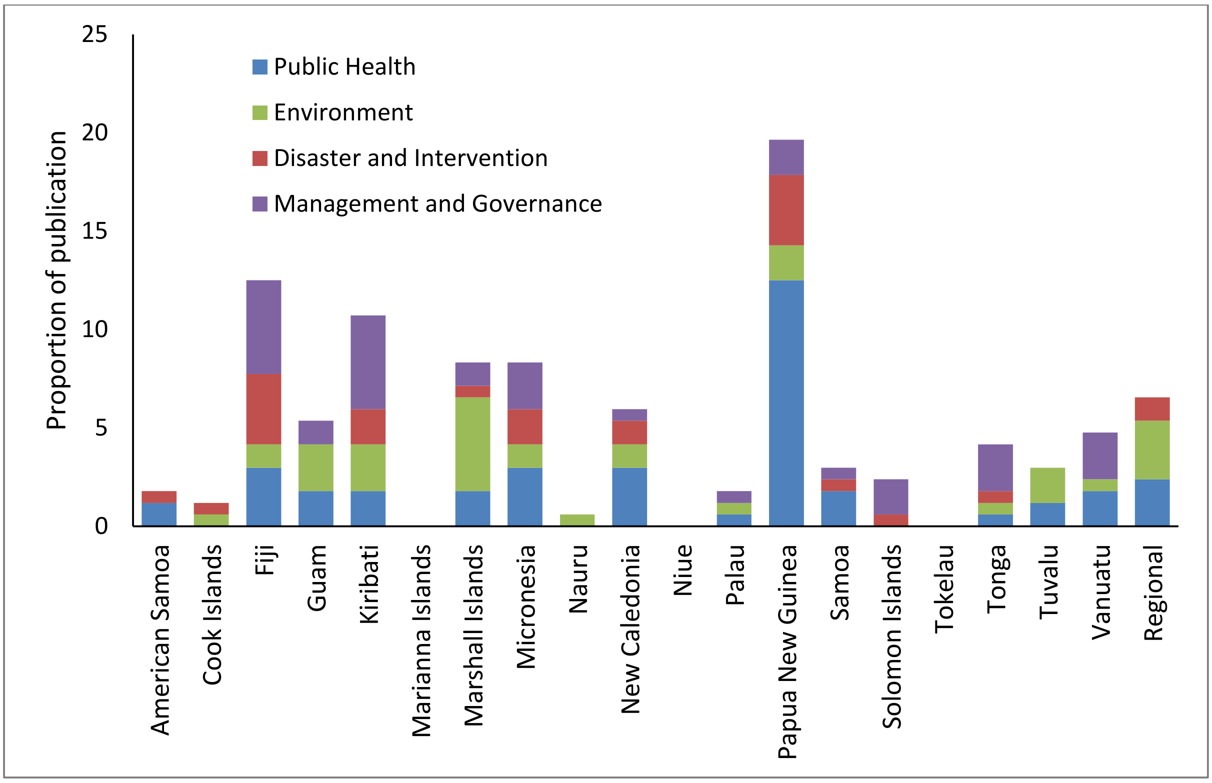

Figure 1.3. WaSH publications by PICs, showing the proportion of publications by country, and the distribution of those publications across the four themes of this review.

Several knowledge gaps emerged from our review of WaSH research in PICs. With respect to environmental studies, which are irrevocably related to public health, there is a strong need for evidence that links open defecation, bottomless septic tanks and other unimproved sanitation options with environmental contamination and the implications of this on human health. Additionally, computerized models of the environment that are designed to predict things like freshwater recharge need to be more inclusive of social factors affecting environmental management, thereby making them more applicable to real-world scenarios.

In light of the impacts and scale of natural disasters often encountered throughout the Pacific region, emergency WaSH responses are often well documented as there is a huge effort to critically assess water and sanitation needs and subsequently mitigate the threat of water-borne disease following disasters (Finau et al 1986; Finau 1987; Dengler & Preuss 2003; Keim 2010; Choudhary et al 2012). Examples of emergency WaSH, which typically focus on water supply, include the provision of bottled water, rainwater tanks and catchment devices and other water treatment methods. Sanitation needs are typically met after the initial emergency response which first aims to secure lives and safety by providing water, food and shelter (Dengler & Preuss 2003). Critically, the disaster response literature lacks a well-rounded assessment of not just the emergency response action, but of the short, medium and long term consequences of emergency WaSH aid. Dengler and Preuss (2003) provide a useful framework for understanding the four stages of disaster recovery, which enables us to highlight where the bulk of the work has occurred, and, where the greatest knowledge and resource gaps remain. The phases and their goals are as follows:

1. Emergency ***Response***: secure life and safety.
2. ***Relief***: provide basic social necessities for survivors. Includes: providing food, shelter and sanitation.
3. ***Recovery***: reconstruct and rehabilitate impacted communities. This includes the construction or restoration of permanent housing, sanitation and water systems, educational systems and restoration of the economic framework.
4. ***Reduction*** of vulnerability: reduce impacts of future disasters. Includes construction methods, land use decisions, education, advance planning for future disasters and warning systems where appropriate.

Many of the papers reviewed focused their attention on disaster response and recovery, however, what is largely missing are the elements of the final two phases, which cover reconstruction and rehabilitation and reducing the impacts of future disasters. Similarly, intervention studies performed in the region are not longitudinal, lacking context-specific and socio-cultural considerations that could provide not only immediate relief following a disaster but offer sustainable solutions to WaSH problems with the potential to reduce the effects of future disasters. Without the two final phases of disaster response and recovery, which sit more in the space of 'development WaSH' than 'emergency WaSH', coupled with limited monitoring and evaluation around the first two phases, the long term prospects for communities recovering from disasters is unknown and unable to be assessed (Figure 1.4).

In the context of sustainable development, which represents a sequence of reconstruction/rehabilitation interventions rather than just "emergency aid" *per se*, it is easy to identify scenarios of when a disaster response intervention can contribute to long-term disaster risk reduction (tsunami risk mitigation), but may simultaneously increase WaSH-related vulnerability. For example, the relocation of coastal villages may reduce exposure to one type of hazard (tsunami), but may increase exposure or sensitivity to WaSH-related hazards, especially if the relocation site has less access to high quality water sources. Another example of an intervention which can increase community vulnerability is provided by Bailey & Jenson (2014), who highlight the importance of extraction of water from the freshwater lens in emergency situations when other water infrastructure is damaged, but also note that the digging of wells in the reef plate diminishes its natural protective function, thus increasing the likelihood of saline contamination of the freshwater lens in future overwash/storm surge events.

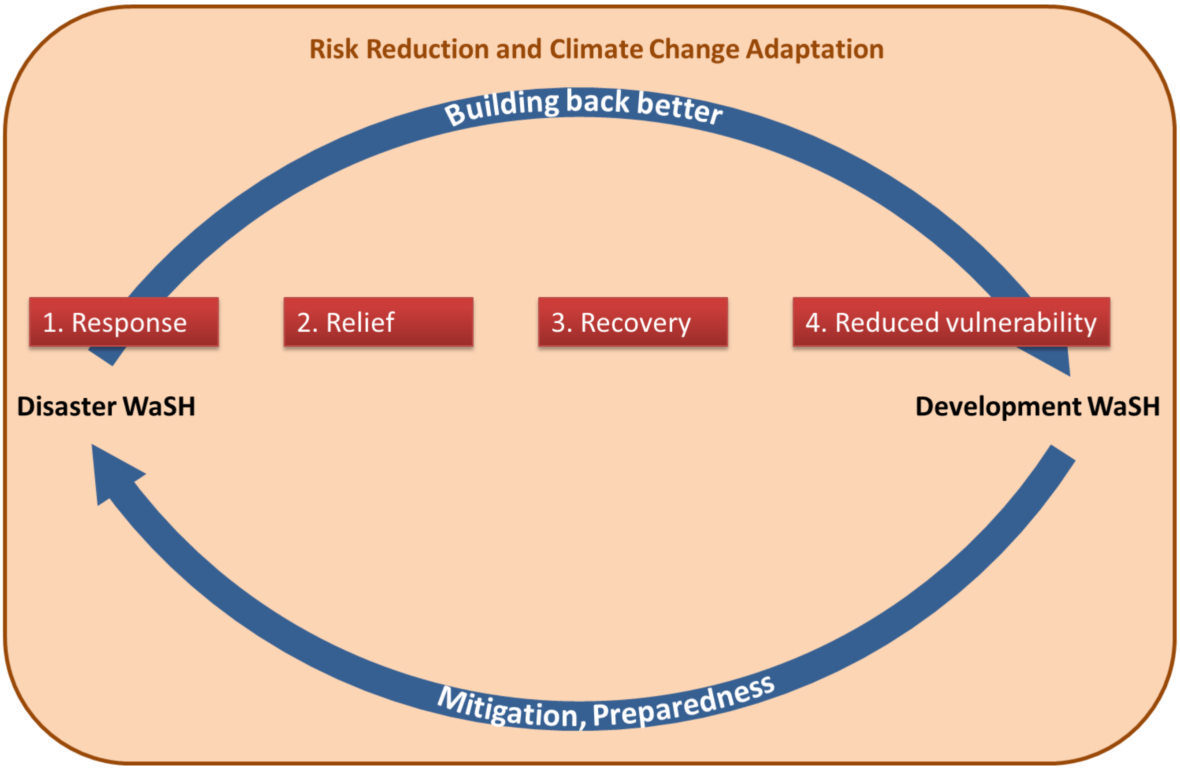

Figure 1.4. Mainstreamed DRR and CCA will lead to improved disaster response and sustainable development if policies and projects work through the 1. response and 2. relief (building back better) 3. Recovery and 4. Reduced vulnerability phases (as identified by Dengler and Preuss 2003). This mainstreaming of climate change impacts and adaptation will build resilience through improved preparedness for future climate-related threats and this will, in turn, support long term sustainable development.

A critical aspect to consider, especially with respect to interventions following disasters, is how easily small, remote and largely rural communities can go from achieving WaSH goals to failing WaSH goals. A single large event can remove infrastructure to the degree that entire communities can permanently lose access to clean safe drinking water, as was the case for a particular study in Samoa (Martin and Watkins 2010). In that study, it was suggested that rainwater harvesting should be adopted both as a failsafe approach following disasters and as a means by which water can be provided to the community while they wait for the infrastructure to be re-built (which is a process that may take several years according to the authors).

The available literature reveals the need for research guided management strategies that prioritize human health and well-being, while concurrently protecting and preserving the natural resources they rely upon for safe drinking water. There needs to be an assessment of different ‘systems’ approaches to WaSH planning and legislation, which include local stakeholders as active and equal participants in the development process, and that harmonize the protection of freshwater resources from ‘ridge to reef’ with an appreciation for the local socio-cultural context.

How to envision and enable climate-resilient WaSH initiatives – Adopting an Integrated Water Resource Management (IWRM) Approach

In order to build community resilience, improve progress towards SDG targets for water and sanitation and negotiate the anticipated impacts of climate change, WaSH activities must be considered in an integrative, holistic way (WHO 2013). One way of tackling this challenge is to consider WaSH (and all other activities) within an integrated water resource management (IWRM) framework. The IWRM framework promotes a process for integrated and inter-sectoral decision-making for water for people and human health (in which WaSH falls), as well as other competing water-use sectors such as agriculture, industry and the environment (GWP 2010). The utility of this approach has been recognized and adopted in the SDGs under Goal 6.5, which states “by 2030 implement integrated water resources management at all levels, including through transboundary cooperation as appropriate” (UN 2015). The approach encourages explicit understanding and consideration of the relationships between all activities in a catchment prior to management intervention (Al Radif 1999). IWRM is a systems approach, rather than a traditional approach which focuses on discrete components of the system, like sanitation, for instance (Al Radif 1999; Biswas 2008).

The IWRM approach is also appealing in that it enables managers to consider WaSH and climate change challenges (and the risks associated with their management solutions) concurrently and not independently of each other – this will be critical in the Pacific region, as climate change impacts threaten the achievement of the SDG targets (Sindico 2016). Indeed, we can contextualize the path towards SDG attainment conceptually as a trajectory that will inevitable be interrupted and disrupted by extreme climate events like droughts, floods, cyclones and storm surge, all of which are common in the Pacific region (Figure 1.5). For many parts of the Pacific region, especially in rural and remote communities, the frequency, intensity and urgency associated with disaster relief WaSH efforts is likely to inhibit progress towards long term and sustained development of WaSH services and infrastructure. Although progress towards sustainable development is occurring, frequent disasters can both detract from those efforts and push developed communities back into a category which again requires significant investment. Indeed, some extreme events will result in massive backward steps in terms of WaSH coverage and access. This has been historically demonstrated in the Pacific region where stories of lost access to water and sanitation services are commonplace (Finau 1987, Mosley et al. 2004, Martin and Watkins 2010). Recognition of the interaction between progress towards development activities and the impacts of climate change is long overdue and it remains to be seen as to how the SDG agenda (UN 2015) and the climate change response agenda, as highlighted in the Paris Climate Agreement (UNFCCC 2016), can be operationally linked and coordinated.

Water management and delivery of WaSH services in challenging contexts like those in the Pacific, and with climate change consequences overlayed, is the kind of complex challenge which falls under the guise of ‘wicked problems’ as described by Rittel and Webber (1973), in that the solutions are not right or wrong, but can rather be characterized as better or worse. The aim of IWRM is to use a holistic systems approach to ensure that management decisions do not push any parts of the system towards the worse end of that spectrum. An integrated assessment of WaSH that includes information about water resources (type, number, volumes, recharge rates, etc.), water protection (water quality), climate change threats to water (floods, droughts, extreme events) and other uses of water will, therefore, generate different, and more sustainable, solutions to WaSH in vulnerable communities. Greater systems understanding will ensure that the implementation of WaSH services will be done in a deliberate and strategic manner, ensuring that management decisions consider resilience of communities, infrastructure, institutions and governance arrangements (formal or informal). A calculated decision to adopt an integrated approach reduces the likelihood of maladaptive interventions and can build resilience in communities to current and future climatic and non-climatic threats (Hadwen et al. 2012).

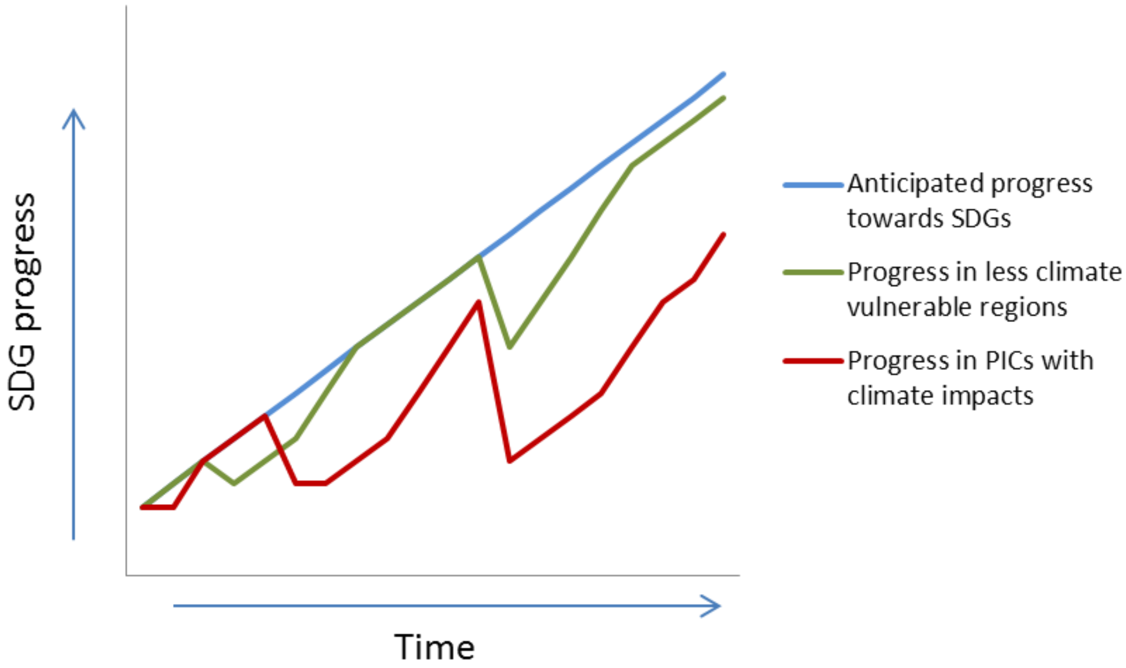

Figure 1.5. Conceptual representation of how climate change impacts, especially extreme events, will affect progress towards the SDGs in PICs and in less climate-vulnerable regions.

PIC communities are already amongst the most isolated and vulnerable globally, and the already difficult task of servicing these communities with water and sanitation is further exacerbated by climate change (Carpenter & Jones 2004). Given this context, it is essential that integrated management approaches are adopted, which incorporate adaptive management based on risk assessments which capture the uncertainty and vulnerabilities in the system of interest (Smits et al. 2009). Furthermore, these integrated approaches must be intersectoral, cutting across all activities which use or influence water. As some countries in the Pacific already show evidence of moving from crisis to crisis (for example, the Marshall Islands which in 2013 suffered emergency drought, and storm surge through the capital), it is also essential that social, economic and environmental systems be considered together, as community resilience will require emergency support and adaptation measures across different areas at different times. Indeed, sustainable and widespread WaSH coverage, by definition, must consider both short term (disaster) and long term (climate change) threats and pressures. IWRM approaches offer significant gains over traditional – single department – approaches in this space, by ensuring that the spatial and temporal scales of interest and understood with respect to how the water resource is being valued, used and subsequently managed (Carpenter & Jones 2004).

IWRM is already well known within the Pacific, with most countries having undertaken diagnostic studies and adopted IWRM Plans with support from international donors (SOPAC 2009). In addition, IWRM has been recognised by the University of the South Pacific, which has been offering a training scheme on this topic, tailored to PICs and their water resource issues, since 2005 (Terry et al. 2007). Whilst a broad appreciation of the value of IWRM has been achieved and a regional strategy to manage water using the IWRM principles has been developed (Carpenter & Jones 2004), large-scale projects adopting IWRM principles have been slow to eventuate at the National level. Indeed, many of the initial demonstration projects supported by SOPAC and GEF were small scale applications which focused solely on a single aspect of water (i.e. water quality or wastewater treatment) (Carpenter & Jones 2004). To this end, some of the projects have not adequately addressed all of the issues that are likely to influence water and its quality and quantity in the study area. Part of this stems from the deliberate focus of the pilot projects on current issues of concern in particular communities in some instances, but there is also growing evidence that IWRM projects throughout the world often do not operate broadly enough to integrate land based activities and their consequences for water (Falkenmark et al. 2014).

In order to tackle WaSH and climate change adaptation in areas like the Pacific, IWRM needs to be broadened and mainstreamed into planning (for all activities) within catchments (Carpenter & Jones 2004, He 2013). This is no doubt a challenge for many PICs, especially since many are characterised as having government administrations with poor capacity and limited communication among and between departments (Carpenter & Jones 2004). Fortunately, there is evidence of a move towards a more holistic appreciation of water resources within the Pacific with the growing support and recognition of 'Ridge to Reef' approaches to managing water and land (GEF 2004, SOPAC 2009, IUCN 2013). This movement towards a catchment-based approach to water management, even in atoll settings within the Pacific, is a critical first step towards a truly integrated application of IWRM principles. Broad regional acceptance of this approach and its support from global organisations and donors (like GEF and the IUCN) mean that the PICs are well placed to adopt approaches that will integrate WaSH and climate change decision making processes.

Conclusions

In order to change the pattern of stagnating and, in worst cases, declining water and sanitation coverage in PICs, interventions must be mindful of how WaSH sits in an increasingly unpredictable water cycle (Barnett 2001). The feasibility of taking an IWRM-based approach to tackle both WaSH and climate change challenges is, therefore, worth considering for the Pacific Region and this is something that has no doubt been strengthened following the inclusion of non-WaSH targets in SDG Goal 6 (UN 2015). Through the adoption of a spatially (ridge to reef) and temporally (past, current and future) integrated approach, based on IWRM principles, PIC communities will be able to develop sustainable practices with respect to WaSH in the medium to long term that do not compromise other aspects of their lives or increase their vulnerability to climate change threats.

Section 2: Enabling environment, WaSH and climate change in PICs

In a region characterised by small economies, scattered and remote islands, and isolated rural communities, PICs struggle to address governance, management, finance and human resourcing challenges for the provision of sustainable WaSH services. Day to day challenges for WaSH service delivery are exacerbated by exposure to climate variability and extreme weather events, including droughts, floods and cyclones, and the longer-term impacts of climate change (UNICEF 2014). Integrating climate and disaster risk reduction and management (DRRM) in WaSH policy and programs, and enhancing coordination between these sectors, is critical for climate resilient and sustainable WaSH services.

Between March 2013 and March 2016, we completed a review of national policies and plans relating to WaSH, climate change and disaster risk management, and conducted key informant interviews with government, civil society, multilateral and climate project stakeholders in the Marshall Islands, Solomon Islands, Papua New Guinea, Fiji and Vanuatu. Key findings from this review of the enabling environment for climate resilience WaSH in the Pacific are discussed below and in two illustrative case studies.

Integrating climate change adaptation and disaster risk management

The impacts of climate change and extreme events are already being felt in communities throughout the Pacific region. Driven by international and regional climate frameworks, and opportunities to access global adaptation funds, PIC governments have developed National Adaptation Plans of Action (NAPA), National Disaster Risk Management Plans (NDRMP), and National Climate Change Policies, to guide sectoral planning and activities for disaster risk management (DRM) and climate change adaptation (CCA).

In recognition of the overlap and synergies between CCA and DRM (including risk reduction), there have been growing efforts at the regional and national levels in the Pacific to bring together what have historically been distinct DRM and CCA policy frameworks and parallel institutional structures, to improve coordination and optimise limited human and financial resources for monitoring, assessment and management of climate and disaster risks. In 2016, the Pacific Islands Forum Leaders endorsed the *Framework for Resilient Development in the Pacific: An Integrated Approach to Address Climate Change and Disaster Risk Management (2017 – 2030).* This Regional Framework outlines voluntary guidelines for PICs to strengthen integration of CCA and DRM in policy and planning, and at all institutional levels, calling for the development of more detailed sectoral programs and plans to promote climate resilient development.

With support from regional agencies and international donors, PIC governments have started to take proactive steps to integrate and rationalise national CCA and DRM policies and plans. The Republic of the Marshall Islands, for example, has developed a *Joint National Action Plan for Climate Change Adaptation and Disaster Risk Management (2014-2018)*, while the Government of Vanuatu has made efforts to align several overlapping policies in the *Vanuatu Climate Change and Disaster Risk Reduction Policy 2016-2030*. In Fiji and the Solomon Islands, lead agencies responsible for CCA and DRM are now housed within a common Ministry.

At the programming level, a number of initiatives are currently underway to strengthen systems, processes and capacity for integrated CCA and DRM, at various levels of government and in communities. This includes, for example, the UNDP funded *Pacific Risk Resilience Program* (PRRP) in Fiji, and the World Bank's *Community Resilience to Climate and Disaster Risks* (CRISP) Program in the Solomon Islands.

Risk reduction and management for climate resilience within the water resources sector

While the impacts of climate change on water security are acknowledged in national CCA and DRM policies and plans, and in some cases, water and sanitation is explicitly identified as a priority sector for adaptation, sector specific strategies and functions[1] and responsibilities for CCA and Disaster Risk Reduction (DRR) are not well defined.

Within the Pacific water resources sector, interconnections between climate change, water availability, water quality and WaSH are well recognised. This has informed a regional push for more holistic and integrated approaches to risk reduction and management within the sector, in order to protect fragile water resources and to improve the availability and quality of water for a range of human uses (including water, sanitation and hygiene) and ecosystem health (Hadwen et al 2015).

In recent years, the SPC Geosciences Program (SOPAC) and international donors have been supporting PIC governments to develop Integrated Water Resource Management (IWRM) Plans and to strengthen the frameworks, institutional structures and processes required for implementation of IWRM and local Ridge to Reef approaches. IWRM promotes participatory, inter-sectoral management of changing water conditions, uses and demands, and in doing so, can strengthen institutional capacity and coordination at all levels to reduce and manage the impacts of climate variability and change on water resources and WaSH systems (GWP 2007).

Large-scale IWRM programs at the national level have been slow to take off in PICs, but increasing efforts to promote the sustainable use and protection of water resources for future generations will contribute to climate resilience. In the Marshall Islands, for example, the *National Water and Sanitation Policy (2014)* mandates that all water management organisations must have an Integrated Water Resource Plan, and adopts Water Safety Planning as a standard risk-based approach to water management in urban centres, with plans to tailor this approach to the more remote outer-islands. In the Solomon Islands, the *Solomon Islands Water Sector Adaptation Project* funded by UNDP and GEF aims to enhance water resource and WaSH resilience at national and local levels by building capacity for and removing barriers to the integration of water resource management, WaSH and climate change adaption, using IWRM approaches.

Climate-resilient water supply, sanitation and hygiene

WaSH programs and activities in PICs are guided by broader national water resource management policies and plans. Functions and responsibilities for water supply, sanitation, and hygiene, in rural and urban areas, are often divided between multiple government agencies with varying levels of coordination. Non-government organisations (NGOs) are actively involved in WaSH service delivery in PICs, particularly during disaster response and recovery, and in rural and remote areas where the reach of National and Provincial governments is limited.

In recent years, detailed WaSH policies and plans have been developed and endorsed in several PICs, including the Republic of the Marshall Islands, Solomon Islands and Papua New Guinea, to improve monitoring, regulation and enforcement of service delivery standards for sustainable WaSH services. Design standards for water supply and sanitation systems have also been adopted in some PICs, such as the Solomon Islands, Fiji, and more recently in Vanuatu, but these standards and community engagement guidelines tend to lack detailed guidance or tools to support climate-resilient design and management.

At the community level, a range of participatory, risk-based management processes and tools are being implemented by government and civil society WaSH, CCA and DRR actors to build the capacity of communities to identify risks, assess adaptation options, and develop risk reduction and management plans. These efforts are largely project-based and implementation is therefore fragmented. Standard community engagement guidelines and tools for climate and disaster risk assessment and management in the WaSH sector could assist to strengthen implementation and coordination. In several PICs, UNICEF has been piloting Modified Drinking Water Safety and Security Planning, as one example of a community-based risk management approach designed to address climate and other risks to water quality and availability.

[1] The term “function” is used to refer to an action or activity of an individual or an institution.

A more strategic and coordinated approach to CCA and DRM in the WaSH sector will require sectoral adaptation plans that clearly outline: 1) the functions, roles and responsibilities of various WaSH actors in relation to CCA and DRM and, 2) processes, guidelines and tools for management of climate and disaster risks. Sectoral adaptation plans could enhance opportunities for coordination between WaSH, CCA and DRRM actors. There is also a need within the WaSH sector to strengthen the linkages between emergency WaSH and development WaSH actors to increase collective efforts towards risk reduction and preparedness.

Case Study: Strengthening the enabling environment for climate-resilient WaSH in the Solomon Islands

Finding 1: Functions and responsibilities for reduction and management of climate and disaster risks

In order to promote resilience to climate variability and change, Rural WaSH policies and plans should clearly define the roles, responsibilities and functions of actors within the sector for reducing and managing climate and disaster risks. *The term "function" is used in this brief to refer to an action or activity of an individual or an institution.*

Defining functions and responsibilities for CCA and DRRM in rural WaSH policies and plans

The Solomon Islands Rural WaSH ("RWASH") Policy, endorsed in 2014, strengthened the focus on sustainability, emphasising sectoral reform and capacity building to enhance coordination at all levels of government, and to increase support for community WaSH management. The RWASH Policy, and related Strategic Plan (2015-2020), clearly outline the functions and responsibilities of government, non-government and community service delivery partners at national, provincial and local levels, for planning and ongoing operation and maintenance of WaSH services. The RWASH Policy addresses daily challenges for sustainable WaSH services, but also acknowledges the impacts of climate change on water availability, and the need for climate resilient technologies and risk management approaches to build adaptive capacity and resilience to current climate variability and future climate change.

Despite this recognition of the need for reduction and management of climate and disaster-related risks, the RWASH Policy and Strategic Plan do not define or address functions and responsibilities for risk reduction or disaster preparedness, response or recovery. Interviews with WaSH actors revealed that risk reduction and preparedness functions are currently not prioritised. One government stakeholder explained why progress towards adopting risk-based management approaches in the national WaSH sector has been slow: "[We] *may not include disaster risk reduction yet because we have so much basics to do. It's essentially implementing.*" Another stakeholder further articulated this challenge, saying "*it's competition between just maintaining service and investing in this risk reduction.*"

In a region prone to natural disasters such as floods, droughts and cyclones, if CCA and DRRM are not well integrated in sectoral policies and plans, stakeholders will continue to engage in reactive modes of disaster management that are ultimately unsustainable, with diminishing returns on investments. There is a recognised need, across all sectors in the Solomon Islands, for more proactive risk reduction and disaster preparedness. As one government stakeholder put it: *"the DM* [Disaster Management] *part of it is all taken care of. The DRR* [Disaster Risk Reduction] *part of it is still a grey area for us".*

Leveraging existing coordination mechanisms to improve linkages within the WaSH sector, and between WaSH, CCA and DRRM actors

Under the National Disaster Risk Management Plans (NDRMP), the WaSH Cluster is responsible for the coordination of risk reduction, preparedness, response and recovery for WaSH, including climate-related risks. There is no mention, however, of the role or functions of the WaSH Cluster in the RWASH Policy, and based on stakeholder interviews, there is a general lack of understanding about the Cluster system. WaSH actors were not aware of any plans or standard operating procedures outlining the functions and responsibilities of the WaSH Cluster, and noted that while disaster response is well coordinated, risk reduction and preparedness functions in the sector are weak. In relation to the WaSH Cluster, one non-government stakeholder noted that "*It usually is active only in disaster emergency time. And after disaster dies down. Everything dies down"*, while a government stakeholder expressed similar concerns: *"we tend to forget anything related to disasters once they're finished and I think that's a mistake…it's only when the WaSH Cluster has been called up again that they start discussing these things and that's delayed."*

The RWASH Policy establishes the WaSH Stakeholder Group as a sectoral coordinating mechanism, however, its functions and responsibilities in relation to reducing and managing both climate and disaster-related risks are not defined. The relationship between the Cluster and the Stakeholder Group, particularly in the transition from disaster relief to the recovery and rehabilitation phase, has not been outlined. In interviews, WaSH actors suggested that the Stakeholder Group could play a more active role in risk reduction and disaster preparedness, for example, through:

- a review of risk assessment tools;
- prepositioning of information, education and communication materials;
- training on how the Cluster System operates; and
- the development of technical standards and community engagement guidelines for emergency WaSH that draw on principles of participation and ownership.

Since the Stakeholder and Cluster groups have similar membership structures, there are significant opportunities for greater coordination between the two.

Figure 2.1 shows the diversity of stakeholders, functions and relationship in managing WaSH and the risks and impacts from climate change and disaster events in the Solomon Islands. This diversity, and the often overlapping functions and responsibilities of actors, can lead to inefficiencies and ineffective programming. Aligning and harmonising institutional structures at the provincial and community level with existing structures established through the NDRMP would promote cross-sectoral capacity building and coordination, and minimise the duplication of efforts. At the local level, for example, Community WaSH Committees are encouraged to establish a disaster team and a response plan, without clear linkages to existing Village, Ward or Provincial Disaster Risk and Response Committees established under the NDRMP.

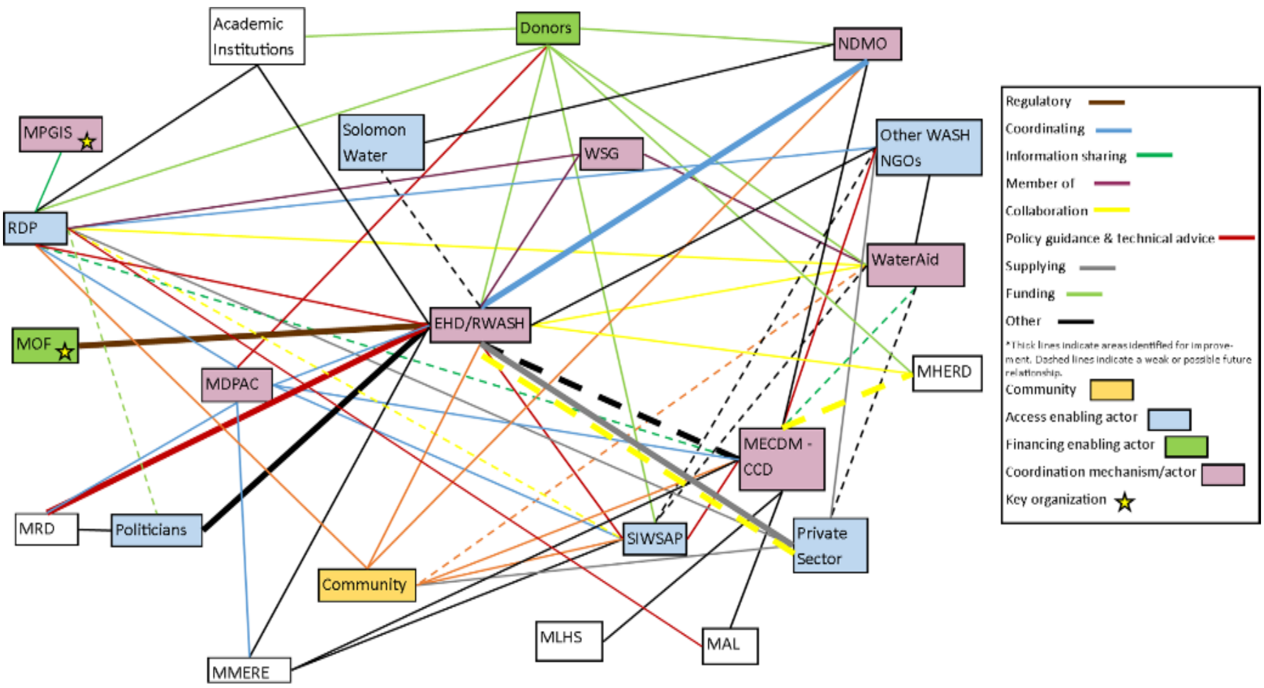

Figure 2.1. Results of participatory stakeholder mapping for climate resilient WaSH demonstrating the complexity of current stakeholder interaction

If functions and responsibilities for CCA and DRRM are clearly defined in WaSH sector policy and plans, this will enable the prioritisation, coordination and resourcing of risk reduction, preparedness and management activities, for more sustainable WaSH services and resilience in response to climate variability and change.

Finding 2: Risk reduction and management approaches for climate resilient WaSH

The RWASH Policy and Plan promotes risk-based management for the protection of water resources and WaSH systems from climate change and other threats; however, no framework or set of guidelines are provided to support the integration of CCA and DRRM in risk assessment and management processes. In interviews, WaSH actors commented that efforts to implement risk-based management approaches are currently fragmented and ad-hoc.

Standardising and coordinating approaches to risk assessment and management for CCA in the WaSH sector

The RWASH Policy and Plan require Service Delivery Partners to carry out a detailed WaSH assessment in their area of responsibility. The revised RWASH Construction and Design standards further mandate that project design reports include consideration of vulnerability to climate change and options for CCA. A clear framework, and set of guidelines or tools, could further support the integration of climate vulnerability assessments in existing design processes.

Government, NGOs and CCA-DRR Programs operating in the Solomon Islands have their own risk assessment tools and approaches to inform planning and management of WaSH, CCA and DRRM. While this suggests a wealth of local knowledge and experience in risk-based management, there is also a lack of consistency. As one CCA-DRR Program stakeholder commented: *"everyone's doing everything segmented and it's different. And everyone thinks they're doing it better than the other, which is a general NGO trait…it's very frustrating, the lack of data and lack of coordination…everyone is reinventing the wheel and having to do it every time."* Standard guidelines would improve the implementation and coordination of risk assessment and management processes for CCA and DRRM in the WaSH sector.

The RWASH Community Engagement Guidelines identify DRR as a key discussion topic during pre-construction workshops in communities, and during WaSH Committee training; however, no process or tools are provided to support the identification of climate-related risks and other threats to the sustainability of WaSH systems, or to assess management options.

There are a number of pilot programs currently underway in the Solomon Islands, and throughout the Pacific region, that are developing and testing frameworks and tools for risk assessment and management planning at the community level, such as modified Drinking Water Safety and Security Planning, and Climate Vulnerability and Capacity Assessments. Lessons from these programs can inform the development of a framework and tools to guide the implementation of risk assessment and management for CCA and DRRM in the WaSH sector.

Finding 3: Institutional capacity building for climate resilient WaSH

Although the need for capacity building to support sectoral reform is identified in the RWASH Policy, capacity building for CCA and DRRM is not emphasised. Functions and responsibilities for CCA and DRRM in the WaSH sector need to be defined in order to more strategically identify capacity building needs.

Linking human resources planning to sector functions and responsibilities

It is widely acknowledged that capacity gaps from the national level down to the provincial and community level are major constraints to the implementation of sustainable WaSH services, along with other development objectives and plans in the Solomon Islands. As one government stakeholder noted, *"we are trying to frame up policies and standards and everything, but we don't have the right people to implement some of those..."* The reality of thin resources and capacity is acknowledged in the RWASH Policy and is the rationale for a shift within the RWASH Program, from direct implementation to contracting, regulating and monitoring Service Delivery Partners.

Defining the functions and responsibilities of sector organisations (as discussed in Finding 1) allows for more strategic human resources planning and capacity building. For example, the functions of the RWASH program have shifted under the RWASH Policy and Strategic Plan, from a focus on implementation of WaSH infrastructure and services to coordination, management and monitoring. While this transition presents challenges, having defined functions allows the RWASH program to systematically identify capacity gaps and strategically build capacity to address daily challenges. Because the RWASH Policy and Strategic Plan do *not* define functions and responsibilities for CCA and DRRM, it will be difficult to identify capacity gaps and to strategically build capacity to address WaSH challenges stemming from climate variability and change.

Build capacity for the identification and management of risks

A clear sectoral framework for risk assessment and management, that integrates CCA (as discussed in Finding 2), would enable more targeted capacity building for climate resilient WaSH at all levels of government. Joint capacity building exercises with national CCA and DRRM actors could also facilitate improved cross-sectoral collaboration and coordination.

Stakeholder descriptions of capacity building activities at the community level often centre around awareness creation and the delivery of training with pre-specified content to community members. This approach to capacity building may not be most effective for building the knowledge and skills required for risk assessment and management, to enhance adaptive capacity. One non-government stakeholder suggested *"let's also move away from training, training, training to facilitation of needs based training. So risk based training."* Guidelines and tools for participatory risk assessment and management planning at the community level should enhance capacity for CCA by strengthening the skills and knowledge required to identify risks, assess CCA options, and plan for and respond to the impacts of climate variability and change on WaSH systems (Civil Society WaSH Fund 2015).

Recommendations

1. In order for WaSH services to be sustainable, they must be resilient to climate variability and change. Rural WaSH policies and plans should clearly define functions and responsibilities for reducing and managing climate and disaster risks at the national government, provincial government and community levels. This should include coordination between the WaSH Stakeholder Group and the WaSH Cluster, in order to strengthen links between disaster and development WaSH, and align with existing institutional structures for disaster risk reduction and management.

2. To enable the implementation of risk management for the protection of water resources and provision of sustainable WaSH services, a framework and clear guidance on methods and tools for risk assessments and management is required. This framework should be endorsed and guidelines developed for the Solomon Islands to promote consistent implementation for climate resilient WaSH.

3. Strengthening institutional capacity for risk management would enhance adaptive capacity to climate variability and change. Targeted training to build capacity for risk management is necessary at all levels of government, down to the community. Joint capacity building exercises with climate change adaptation (CCA) and disaster risk management (DRM) actors could also improve cross-sectoral partnership and coordination.

Case Study: Current policy and institutional structures for integrated WaSH, CCA and DRM in the Republic of the Marshall Islands

Methods

Data used in this case study is drawn from a review of key WaSH, CCA and DRM policy documents, and interviews conducted with stakeholders in Majuro in November 2014.

Finding 1: An enabling environment for climate-resilient WaSH

Integrating WaSH, CCA and DRM policies and plans

The RMI is amongst the first PICs to have taken proactive steps towards policy integration for CCA and DRM by developing a *Joint National Action Plan for Climate Change Adaptation and Disaster Risk Management 2014-18* (JNAP). This recently endorsed plan brings together the strategic goals and objectives of the *2011 National Climate Change Policy Framework* (NCCPF) and *2008 National Action Plan for Disaster Risk Management* (NDRMP).

The benefits of adopting a more integrated approach to CCA and DRM include:

- strengthening coordination and rationalising institutional and policy arrangements;
- minimising the duplication of efforts, and optimising limited resources;
- bringing together different funding sources; and,
- improving decision-making and risk management processes for disaster and climate risks.

The JNAP does not provide detailed sectoral guidance on adaptation and risk management, but rather, calls for the integration of CCA and DRM activities into sectoral policies, work plans and budgets, and for capacity building within each sector to support participatory and integrated approaches to risk assessment and management.

In relation to WaSH, the JNAP identifies limited and fragile water resources, poor sanitation and high rates of contamination as key drivers of vulnerability to climate change in the RMI. Storm surges, king tides, typhoons and droughts are identified as having serious impacts on water resources across the atoll country, including the inundation of vital freshwater lenses. While the NCCPF identified water security as one of nine national priority areas for adaptation, it is no longer a standalone goal in the JNAP, however, Goal 5 of the JNAP relates to enhanced local livelihoods and community resilience, and includes reliable access to clean water, the reduction of vulnerability to water-related hazards, and reducing the impacts of climate change on water resources.

The NWSP was endorsed in 2014, prior to the finalisation of the JNAP, but nonetheless supports the objective of CCA and DRM mainstreaming in the WaSH sector. Building resilience to climate variability and extreme events by "*ensuing water and sanitation provision through proactive risk reduction and comprehensive monitoring*" is one of five core policy goals outlined in the NWSP.

Identifying frameworks to guide climate and disaster risk management

To support an integrated and holistic approach to WaSH management that includes the protection of water resources from climate and other risks, the NWSP IWRM. Policy Target 2 states that "*By the end of 2015, all water management organisations shall have an integrated water resource plan*", including Community Water Committees. These Committees will be comprised of local water users and other local stakeholders, supported by a National Water and Sanitation Office, which will be established and resourced by the Environmental Protection Agency (EPA), to lead coordination and implementation of the NWSP. A Water and Sanitation Commission will provide governance support and oversight, with representatives from all key stakeholder groups.

The adoption of an IWRM framework should enable participatory management of changing water conditions, uses and demands, through strengthening institutional capacity and coordination at all levels of government, and in the community, in order to reduce and management the impacts of climate change and other risks to water resources and WaSH systems (GWP 2007).

The NWSP identifies Water Safety Planning as the framework to support implementation of a proactive approach to risk management in the WaSH sector. The five-year NSWP Action Plan includes the development of a comprehensive National Water Safety Plan for major urban centres and the outer islands, using a simple, clear, and objective risk assessment system. This process will be led by the National Water and Sanitation Office, who will also be responsible for the development of a comprehensive monitoring program to ensure that data is readily available to inform decision-making for resource management and risk reduction at the national and local levels. A Water Safety Plan has already been developed for Majuro, but was not available for review at the time of this study. Having a clearly defined framework for risk management in the WaSH sector will enable improved coordination and allow for more targeted capacity building activities to support climate resilient WaSH.

Finding 2: Strengthening preparedness, response and recovery functions

Developing an Emergency Response Plan and Standard Operating Procedures for the WaSH sector

The JNAP calls for development of Emergency Response Plans and Standard Operating Procedures in each sector, with individual Ministries responsible for the procurement of emergency resources and pre-positioning to support implementation of these plans. The need to develop a disaster and emergency plan, and early warning systems is also identified in the NWSP Action Plan, but at the time of interviews, stakeholders were unaware of progress towards this objective.

When it comes to preparing and responding to disaster events, the NWSP identifies a handful of discrete preparedness activities, such as storage and regulation of water use to ensure availability in times of drought, rainwater harvesting, and the establishment of early warning systems. However, no processes, functions or responsibilities are outlined for a coordinated approach to disaster preparedness, response and recovery within the sector. As one government stakeholder highlighted, there is a need to review the NWSP from a disaster management lens: "*we need to look at what's in there. What are the arrangements in there in terms of DRR, in terms of CCA*".

There is also no mention of the WaSH Cluster and its risk reduction, preparedness, response and recovery functions within the NWSP. This Cluster is a relatively new coordination mechanism, activated for the first time in response to the 2013 drought. Previously, the United States' Federal Emergency Management Agency was responsible for disaster management in the RMI, however, in 2008 this role was handed over the United States Agency for International Development, who channeled funding for the drought response through the implementing partner International Organisation for Migration. The Cluster was led by the Majuro Water and Sewer Company, with a focus on conducting damage assessment surveys and the distribution of Reverse Osmosis (RO) units for desalination.

Reducing dependency and building adaptive capacity through disaster preparedness, response and recovery

Stakeholders interviewed for this study commented on the history of emergency interventions by external actors in RMI and the dependency this has fostered. As one stakeholder explained, it is not lack of capacity, but rather, a lack of awareness and understanding of functions and responsibilities for disaster preparedness, response and recovery at the national, local and community levels: *"that traditional knowledge [for adaptation and disaster preparedness] is still there and used, but I think it's more recently the creation of a dependency state"*. Another stakeholder similarly noted that *"when a disaster does happen or an emergency, people react, people do things. It could be more efficient, and they're really good at a couple things, but preparedness is not one of them".*

The absence of an Emergency Response Plan and Standard Operating Procedures in the WaSH sector appears to compound this challenge: *"your standard preparedness state – and that would include who reports rainwater levels, who receives that report, weather station – well that's not written down in anybody's responsibilities anywhere."* Another stakeholder summarised what is needed: "*a better understanding from everyone about what they can do, preparing, responding, recovery. What everyone can do in those different places".*

With functions, responsibilities and guidelines for disaster preparedness, response and recovery not clearly defined or formalised in any policy or plans, activities are more likely to be ad-hoc, and monitoring and regulation of WaSH interventions during emergencies is unlikely to occur. This can lead to emergency response actions that reinforce dependency in communities and increase vulnerability to extreme events and climate change. Opportunities to build resilience in the preparedness, response and recovery phases of a disaster are likely to be missed. As one stakeholder explained *"Sometimes the interventions that happen here I'm worried about, because it doesn't take into account, or it doesn't show people their own resilience, and how they can be a key actor, you know? They're the first responders, and that type of thing".*

Several examples of the ad-hoc and uncoordinated approach to disaster response were identified during interviews. One stakeholder commented on the delivery of rainwater tanks to communities as part of the drought response, where there was limited training or information provided to support construction, ongoing operation and maintenance, and the regulated use of these facilities as an emergency drinking water source. Another example related to the provision of RO units and the need for guidelines to inform when and how this approach should be used. One stakeholder described the problem of dependence on RO and the need to consider multiple sources of drinking water: "*instead of trying to improve their rainwater harvesting systems, which are low cost and effective and can store more water, if you assume that in the event of a drought they're going to send you an RO or, if you [already] have one, as soon as it breaks, you're done. If you're not also having another coping mechanism for drought or dry seasons, and you're just depending on an RO, the second that RO breaks then there's no other water source.*"

The development of an Emergency Response Plan and Standard Operating Procedures for the WaSH sector, and clearer articulation of the functions and responsibilities of other stakeholders in disaster preparedness, response and recovery, would promote a more coordination approach to disaster preparedness and response in the RMI WaSH sector.

Finding 3: Coordination and capacity building to support implementation

Implementation of the NWSP depends largely on the establishment and adequate human and financial resourcing of the National Water and Sanitation Office. In addition, the Office and its partners will need to support capacity development at all levels of government and in the community in order to facilitate participatory IWRM and WSP processes, and regulate and monitor the WaSH sector.

Capacity building for climate adaptation and risk management at the local level

According to the NWSP, for daily management of WaSH services, Community Water Committees comprised of various local stakeholder and user groups will be established. These Committees are also responsible for a range of actions designed to increase adaptive capacity and risk management for climate variability, including monitoring and regulating water use and contamination, promoting diversification of water sources, and developing and managing a local IWRM plan.

Households in communities will be responsible for the provision and maintenance of their own improved water and sanitation facilities, which the NWSP states should be resilient to drought and extreme weather events, and designed to prevent contamination. The Ministry of Public Works is currently developing a building code that will include standards for household sanitation, while the Ministry of Health will promote improved household water and sanitation through behaviour change and social marketing campaigns.

The National Water and Sanitation Office, as the lead institution for the implementation of the NWSP, will be responsible for coordination, public communication and awareness raising, water quality monitoring at the national and local level, and development of the National Water Safety Plan. The NWSP suggests that most implementation at the household and community level, including capacity building and community outreach will be led by the National Water and Sanitation Office, however, there is insufficient detail in the NWSP and associated Action Plan on functions and responsibilities for implementation. These activities are likely to include capacity building and community outreach.

Cross-sectoral coordination for policy implementation

Opportunities exist to align activities and for cross-sectoral coordination between WaSH actors and those responsible for CCA and DRM under the JNAP, to enhance implementation of the NWSP. NGOs and Multilateral Agencies are active in the RMI WaSH sector, particularly during emergency response and as members of the WaSH Cluster group. The International Organisation for Migration, for example, in addition to playing a leading role in the 2013 drought response, has developed a GIS database mapping water resources across the country. The Majuro Water and Sanitation Company, alongside the Department of Resources and Development, are tasked with supplying all households in RMI with a rainwater tank for emergency water supply. The development of community preparedness and response plans, and public awareness on basic emergency response procedures, are identified as key activity to be led by the Chief Secretary’s Office (CSO). Despite this level of engagement, the role of these organisations, and how they link into processes and institutional structures within the WaSH sector, is not articulated in the NWSP.

In interviews, stakeholders reported that there are no systematic processes for monitoring, regulation and coordination of NGOs and donors in the WaSH sector, and that this can create challenges for communication and coordination. As one stakeholder commented, when discussing the contribution of their organisation to WaSH, CCA and DRM sectoral plans: *“who can I report this to, that I'm helping you meet your National Strategic Plan?...We are doing work that's helping with these plans and obviously we want to, we want it to be what the government wants".*

Section 3: Understanding WaSH in remote communities and exploring the climate resilience of systems

One of the great challenges associated with understanding the use of WaSH services and prioritising development needs in rural communities is the lack of data. In this project we sought to address this lack of data through the development of tools to enable data collection and analysis. We sought to use these tools to enable a systems approach to understanding WaSH in remote and rural communities, to inform WaSH system analysis and provide critical content to support a decision making tool (refer to Section 4 for details of the BBN model).

Underpinning the development of our framework to aid decision makers is the data we have collected from communities in the Pacific. In this section we an overview of our approach to data collection and the findings derived from household (HH) surveys and focus group discussion (FGD) sessions in remote and rural communities in the Solomon Islands (SI) and the Republic of Marshall Islands (RMI).

3a. Using digital surveys to increase the size, representativeness and reliability of your data-set

Background

Most surveys conducted for global water, sanitation and hygiene (WaSH) research and evaluation neglect aspects of HH water management that are widespread and essential in many developing country settings. Indeed, evaluations have an exclusive focus of HH surveys on the “primary” source of water for drinking and cooking (Bartram et al. 2015). This has led to the underrepresentation of multiple water source use and its importance with respect to HH water management, particularly with respect to the adaptation of water use practices by season and in response to extreme climatic events. Understanding multiple water sources and their patterns of use by households represents a significant aspect of the adaptive capacity and climatic resilience of households and communities. We, therefore, concentrated our efforts to capture information and develop an understanding of multiple water source use in the communities we worked with in this project.

Methods

To examine multiple sources and their uses, including changes in use with season and extreme events, we sought to adopt and modify a survey developed by Whittington (2000). While the data generated by this survey is considered the gold-standard in the differentiation of multiple water sources and uses, it hasn’t been widely adopted by researchers or assessors because it is considered too time consuming and difficult to implement as a result of its intricate grid-pattern framework, numerous skip sequences and extensive length (Figure 3.1). For these reasons, we employed a mobile computer assisted protocol to increase delivery speed and make the survey easier to use.

SN	SOURCES OF WATER IN THIS VILLAGE OR COMMUNITY.	9. In the rainy season, do you use water from …SOURCE… for the following activities? (RECORD ALL THAT APPLY) WATER USED: (1) AT SOURCE (2) IN THE HOME (3) BOTH 1 and 2 (4) NOT USED							10. Do any of these water uses from …SOURCE… differ in the dry season from the rainy season? (1) YES (2) NO (>>12)	11. In the dry season, do you use water from …SOURCE… for the following activities? (RECORD ALL THAT APPLY) WATER USED: (1) AT SOURCE (2) IN THE HOME (3) BOTH 1 and 2 (4) NOT USED							12. Have any of your water sources ever been unsafe to drink because of: 1) HUMAN FAECES CONTAMINATION 2) ANIMAL FAECES CONTAMINATION 3) HELMINTHS (WORMS) 4) SALTY TASTE 5) OTHER: ______
		1. DRINKING	2. COOKING	3. BATHING	4. WASHING	5. ANIMALS	6. FARMING	7. OTHER		1. DRINKING	2. COOKING	3. BATHING	4. WASHING	5. ANIMALS	6. FARMING	7. OTHER	
1	Lake																
2	River																
3	Public taps																
4	Public Well ☐ Electric pump ☐ Rope and bucket																
5	Private well ☐ Electric pump ☐ Rope and bucket																
6	Rainwater (shared) ☐ Communal ☐ Households (#___)																
7	Rainwater (private)																
8	Natural spring																
9	Bottled water																

Figure 3.1. Screenshot of the detailed matrix of the paper-assisted personal interview (PAPI) survey.

The original PAPI (paper assisted personal interview) survey used in this study evolved from a questionnaire designed to investigate multiple water sources and uses within HHs. We expanded the survey from 44 questions and 11 pages to incorporate elements on location of use, and the impact of extreme events such as flood, drought and cyclones on HH water management. These changes substantially increased the length and complexity of the PAPI version, adding 52 questions and 3 pages. The CAPI (computer assisted personal interview) survey was designed to increase the quality of data collection, and facilitate its ease of use by local research staff. In order to reduce the number of data entry errors, the CAPI used embedded skip patterns that automatically triggered questions contingent on earlier responses. The initial investment required to construct the CAPI was substantial, but the open data kit platform employed by SurveyCTO uses a streamlined Microsoft Excel interface that reduces barriers and increases accessibility relative to other CAPI programming interfaces (Caviglia-Harris et al. 2011).

The CAPI survey we developed incorporated a handheld user-friendly interface that allowed researchers to design, upload, field-test and modify electronic questionnaires for a complex HH water management study in remote PIC communities (Figure 3.2). The 17.8 cm high-definition screen made visualization possible even in direct sunlight, and the 317.5 g tablet was easy to carry, less than the weight of ten paper surveys. CAPI also provided greater data security, with fieldworkers able to save and store completed survey responses on laptops and external hard drives. Access to a reliable power source can be problematic in areas without access to a reliable source of electricity. However, the enclosed lithium-ion battery was capable of up to ten hours of fieldwork, but required periodic recharging. In remote and isolated communities throughout the Pacific, our battery charging arrangement varied according to local circumstances, and included solar panels, diesel generators, and vehicle power supplies.

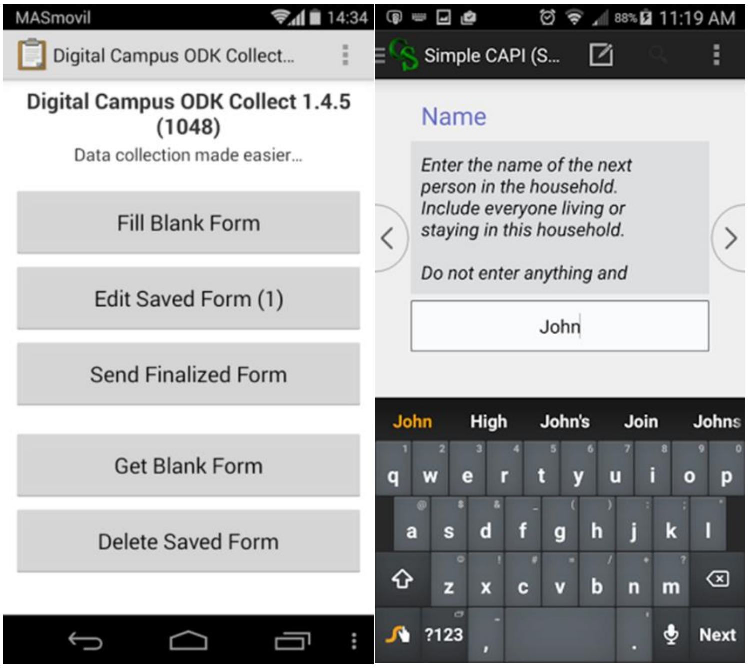

Figure 3.2. Screenshots of the user interface of the computer assisted personal interview (CAPI) survey.

Six local enumerators, three in the Solomon Islands (SI) and three in the Republic of the Marshall Islands (RMI), attended three full days of detailed instruction and practical exercises. After training and prior to data collection, the PAPI survey was field tested in Nomoliki, a peri-urban community of Honiara (SI), and the CAPI survey was field tested in Jenrok, an urban community of Majuro (RMI). Adjustments were made to improve question clarity, facilitate delivery, and troubleshoot any technical issues with the CAPI. The survey was conducted in five communities in SI and eight communities in RMI between August 2014 and November 2015. The CAPI version was implemented in three communities in SI (HHs n=56) and eight communities in RMI (HHs n=235). Two communities in SI received the PAPI version (HHs n=44) before the study transitioned to CAPI. Table 3.1 presents an overview of the data collection effort.

Table 3.1 Overview of data collection effort, across eight RMI and five SI communities.

Country	Community	Island	# HHs Surveyed	Total # HHs	% Coverage	Focus Groups
RMI	Ailuk	Ailuk	40	40	100.0	2
RMI	Wotje	Wotje	40	60	66.7	2
RMI	Likiep	Likiep	35	40	87.5	2
RMI	Ujae	Ujae	43	45	95.6	2
RMI	Lae	Lae	41	43	95.3	2
RMI	Arno	Arno	33	35	94.3	2
RMI	Laura	Majuro	34	100	34.0	2
RMI	Jenrok	Majuro	33	90	36.7	2
	ALL		299	453	76.3	16
SI	Suaghi	Guadalcanal	20	80	25.0	2
SI	Verahue	Guadalcanal	24	60	40.0	2
SI	California	Malaita	17	18	94.4	2
SI	Radefasu	Malaita	21	21	100.0	2
SI	Aifera	Malaita	24	24	100.0	2
	ALL		106	203	71.9	10

CAPI facilitates the delivery of complex questionnaires

We found that data accuracy and reliability was substantially improved with our CAPI surveys, with fewer data entry errors than those observed when the same survey was performed using PAPI methods (Figure 3.3). Drop down menus, mandatory entry fields and nested skip patterns create an easy to use CAPI interface for enumerators with varying levels of experience that resulted in fewer data entry errors and missed responses.

A comparison of CAPI and PAPI methods also revealed much shorter delivery times using CAPI. CAPI surveys required a mean of 32 minutes and 22 seconds to perform (SD = 19 min 11 sec), and varied by enumerator and experience. Linear regressions performed on individual enumerator data revealed intercept values, or average initial survey times between 40 min (95%CI: 24.0 – 58.9) and 49 min (95%CI: 33.7 – 56.1), which and decreased by 10.3 sec per survey (95%CI: 7.2 – 13.4, $p < 0.0001$). As enumerators became more experienced with CAPI, they required less time to deliver each subsequent survey (Figure 3.4). CAPI survey times decreased by approximately 17 minutes between the 1st and 100th survey performed by enumerators.

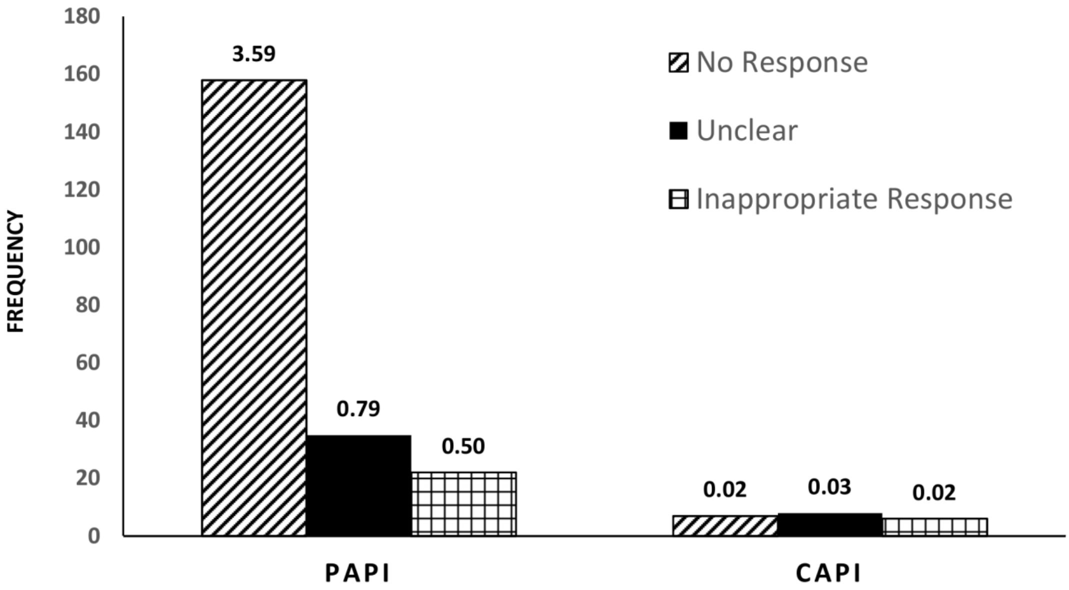

Figure 3.3. Lower error rates were found in the CAPI surveys, highlighting that in addition to time savings, data quality was much improved through the use of the tablet-based survey instrument.

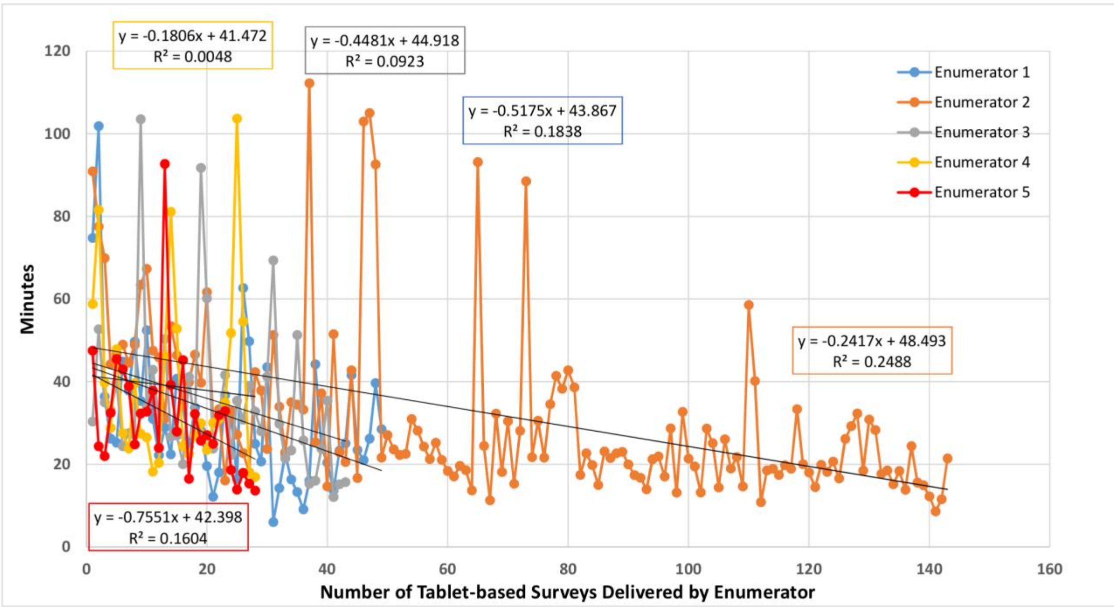

Figure 3.4. Evidence of improved survey speed with increased enumerator experience across the 5 local enumerators employed in SI and RMI.

Conclusions

Equipping researchers and practitioners with CAPI provides decision makers with higher quality data and, therefore, a better understanding of the local context.

The often-stated challenges with collecting complex multiple source data from rural communities certainly represent a barrier to data collection and quality assurance using PAPI methods. However, we have demonstrated that the development of CAPI approaches can enable fast and reliable data collection in some of the most remote communities in the Pacific. We emphasise that the utility of this data should not be underestimated as we move away from 'primary source' towards a much more holistic and nuanced understanding and appreciation of water systems and their use in rural communities. Looking ahead and through the lens of the SDGs, the adoption of multiple water source surveys through CAPI has the potential to enable large-scale regional surveying capable of characterizing multiple water sources, and generating more advanced datasets that are better equipped to inform water, climate change and development policy.

3b. Application of a digitised survey to evaluate multiple household water sources in PICs - a traditional strategy for addressing rainfall variability

Background

As mentioned above, there is growing concern around the use of 'primary source' with respect to understanding water systems, and WaSH generally, in rural communities. While there exists some recent evidence on the presence and use of multiple water sources at the household level (Evans et al., 2013; Shaheed et al., 2014; Ozdemir et al., 2011), there remain considerable gaps in our knowledge of household water management practices, how it varies by season, and how these practices can impact vulnerability to climate change. These latter aspects are particularly important in the Pacific region and particularly relevant to the objectives of this project, to ensure that climate resilient WaSH services can be developed in climate vulnerable communities.

Methods

Data reported here were gathered during 405 household interviews in thirteen PICs communities. In the drought-prone atoll country of RMI we carried out 299 household interviews across eight communities. In SI, we conducted 106 household interviews across five flood-prone communities.

Finding 1: Nearly all households used multiple sources of water to meet their daily needs

Routine use of multiple household water sources to meet daily needs is widespread in PICs. Over 90% of households surveyed in RMI and SI reported using more than one source of water to meet their daily needs. The average number of different sources used per home was, in fact, 2.55. In SI, the number of water sources varied from 2 to 5 (mean 3.14), and in the Marshall Islands, the number of water sources varied from 1 to 4 (mean 2.32) (Figure 3.5). The few households in RMI that reported only one water source relied solely on private rainwater collection.

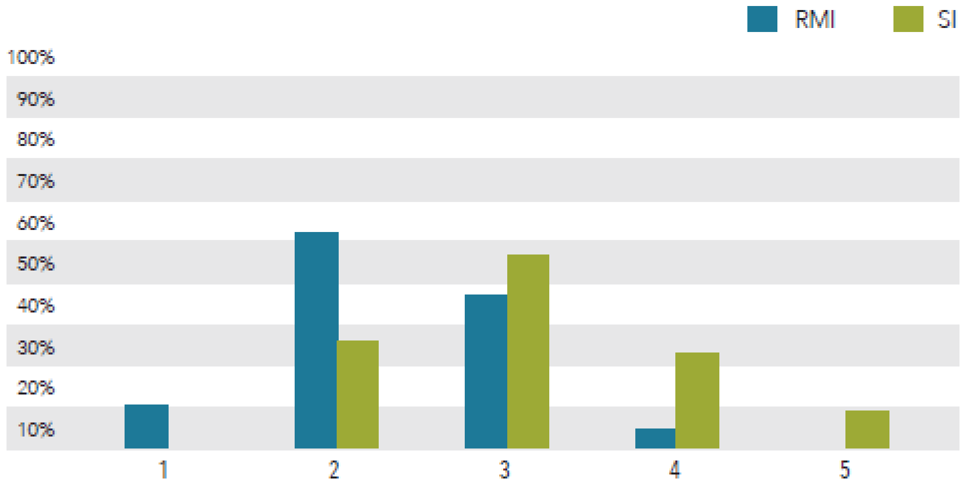

Figure 3.5. Number of regular household water sources used, as reported through 405 HH surveys conducted in the Republic of the Marshall Islands (RMI) and the Solomon Islands (SI).

Typical water use patterns varied between the countries. In RMI, the typical household relied on private rainwater for drinking and cooking, and had a private well that was used for non-consumptive purposes. In contrast, in SI household water sources and uses were much more diverse (Figure 3.6).

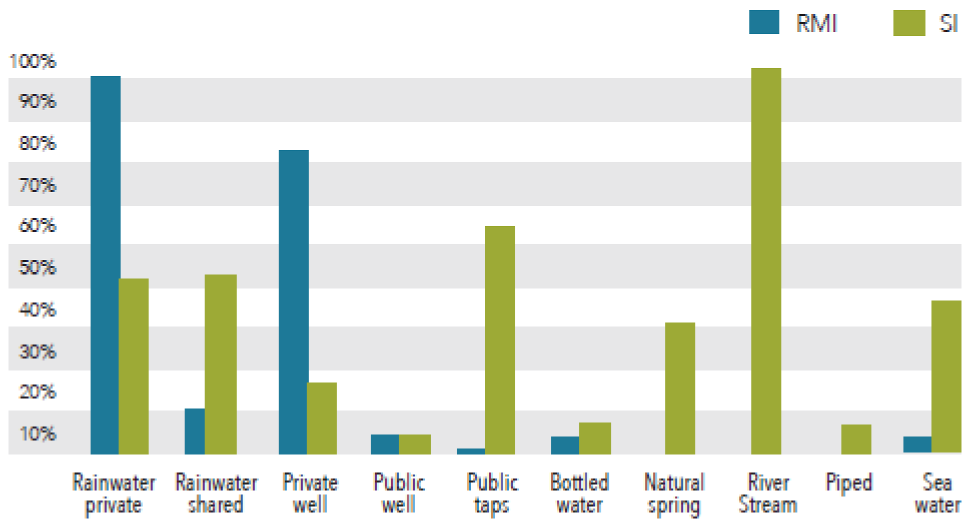

Figure 3.6. Percent of households from RMI and SI reporting use of these water sources in either the wet or dry season.

Finding 2: The primary water source is inadequate indicator of household water sources

Although most research, surveys and datasets focus on the primary source of drinking water, the daily use of multiple sources is widely practiced and essential in many PIC communities. Determining the "primary source" of drinking water for a household is therefore inadequate for measuring resilience to climate variability.

The use of different water sources for drinking varied greatly within study communities in the Marshall Islands and the Solomon Islands, and was also highly variable between the countries. In RMI, private rainwater use accounted for the vast majority of drinking water use throughout the year. This reflects the choice of many RMI households to limit rainwater use during the dry season to consumptive uses only (Figure 3.7). In contrast, diverse sources are used for drinking water in the Solomon Islands, with only public standpipes used by a majority for drinking at any time of year (Figure 3.8).

Finding 3: Seasonal variation of household water sources varied across study communities

In many settings, household-level water sources and uses differ greatly by season. Household water sources and uses varied little across seasons in the RMI communities (Figure 3.7), whereas in the Solomon Islands, sources and uses varied widely by season (Figure 3.8). These differences are likely to have evolved based on historical water availability and rainfall patterns experienced by the study communities. In SI communities, drinking and cooking using water from rivers, springs, public taps and private wells all increased substantially during the dry season, whereas consumption of rainwater (the preferred source in the wet season) decreased substantially (Figure 3.8). Climate change may jeopardize the adequacy of historical household water practices, however, the use of multiple water sources can improve the ability, and opportunity, to adapt to climate variability.

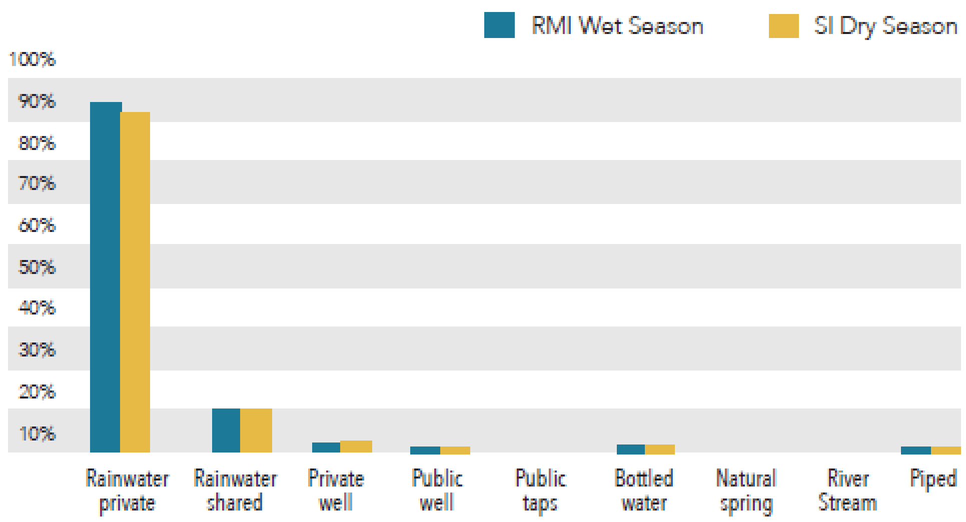

Figure 3.7. Percent of households *drinking* each of these sources in RMI in the wet season and the dry season.

Comparing Figures 3.7 and 3.8 reveals a stark difference in drinking water sources versus water sources used for any purpose. This underscores the inadequacy of focusing on the primary source of drinking water in settings where such diverse sources and uses exist.

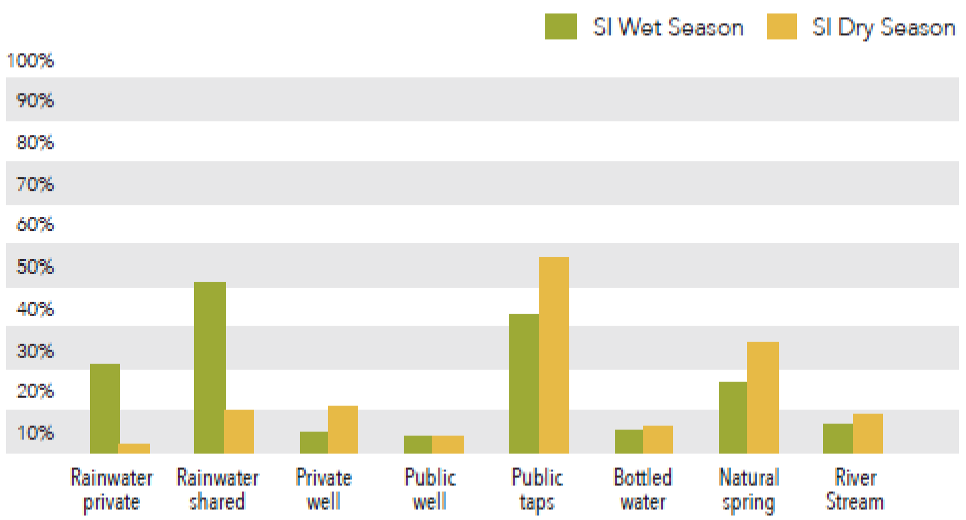

Figure 3.8. Percent of households *drinking* each of these sources in SI in the wet season and the dry season.

Finding 4: Increasing private rainwater storage volume can enhance resilience

Increasing private rainwater storage volume can enhance climate resilience and will likely also reduce water-related health risks. In a typical RMI home, large (800-3000L) private rainwater tanks were used primarily for consumptive (drinking and cooking) purposes with private wells most commonly used for non-consumptive needs throughout the year. RMI households reported the ability to ration stored private rainwater for consumptive uses throughout the dry season. This is consistent with findings from other settings like southern Vietnam where the dry season lasts many months (Ozdemir et al., 2011). In both RMI and SI, many of the households surveyed report that they wash their hands at a source away from home (e.g. river) during the dry season. This practice almost certainly leads to a substantial reduction in the frequency of handwashing at critical times.

In contrast to study communities in RMI, the use of private rainwater declined by almost 90% in the dry season in SI. Private rainwater collection was typically informal, using small pots and pans; while rivers, public taps, shared rainwater tanks, and private wells were widely accessed for a variety of consumptive and non-consumptive uses. Increasing private rainwater storage volume in the Solomon Islands would increase resilience to climate change by providing households with the option to ration stored rainwater for drinking and cooking throughout some or all of the dry season. It would also provide a potential source of handwashing water at the home.

Recommendation

Implementers should consider increasing household-level rainwater storage to improve both household-level and community-level resilience. The lack of private rainwater storage capacity in SI reduces potable water options for households during dry periods, forcing many to consume water from unimproved sources. Providing large rainwater tanks to individual households in SI could both decrease vulnerability to climate change and enable access to an improved water source through some or all of the dry season.

3c. Understanding sanitation practices and priorities in remote PIC communities

Background

Sanitation practices in the Pacific region continue to lag behind progress made in other regions of the developing world (WHO and UN 2014). There have been a number of reasons put forward to explain the lack of progress and there is no doubt that remoteness and a high proportion of rural communities contributes to this challenge.

In the context of climate change and the IWRM systems approach we have adopted in this project, it is critical to evaluate current sanitation practices and priorities to determine what the best sanitation alternatives might be in the remote rural communities throughout the Pacific. This is particularly important given that sanitation practices which concentrate human waste (and pathogens) can pose a risk to water resources – this means that an understanding of local hydrology, geology and sanitation practice is needed to inform both current understandings and to plot the oath toward improved sanitation access and sustainability.

Methods

Data reported here were gathered during 405 household interviews in thirteen PIC communities. In the drought-prone atoll country of RMI we carried out 299 household interviews across eight communities. In SI, we conducted 106 household interviews across five flood-prone communities.

Finding 1 – lots of different sanitation practices in PICs

There were six commonly reported sanitation options in RMI – three representing open defecation - ocean, beach and bush – plus the improved sanitation options of pit latrine, pour-flush toilet and flush toilet (Figure 3.9). In addition to these options, SI respondents indicated that open defecation into rivers or streams was also practiced, although the frequency of use was highly variable across communities.

Sanitation options ranged from unimproved to pit latrine, pour-flush and flush toilets in almost every community. Overall, the Open Defecation (OD) practices ranged from being a very common practice in Suaghi, SI where >97% HH reported practicing OD, to being completely absent in Likiep, RMI. OD was reported from a higher proportion of households in SI (64%) than in RMI (27%). In terms of improved sanitation facilities, 60% of the RMI HH reported using either pour-flush or flush toilets – in contrast these sanitation options were used by just over 13% of the HH in SI.

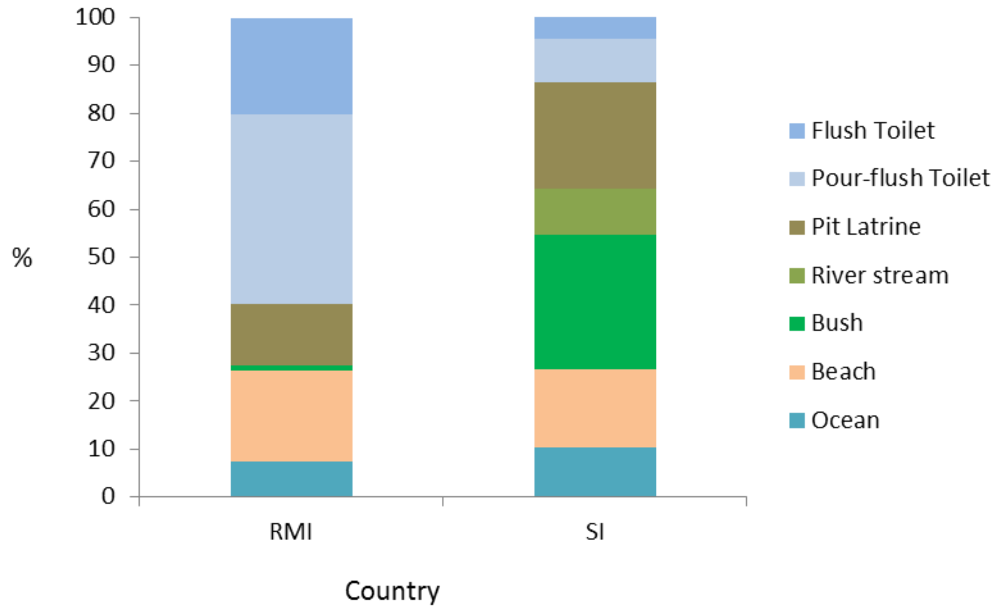

Figure 3.9. Percent frequency of reported sanitation practices in RMI and SI communities.

Sanitation services and practices varied widely by community in both SI (Figure 3.10) and RMI (Figure 3.11), reflecting different levels of intervention and development throughout the regions surveyed. Interestingly, many remote RMI communities were found to have relatively high levels of improved sanitation services despite having access to fewer water sources than most SI communities; however, there is a suspicion that reported access to and use of improved sanitation options was over reported in some of these RMI communities (see earlier section on multiple water sources).

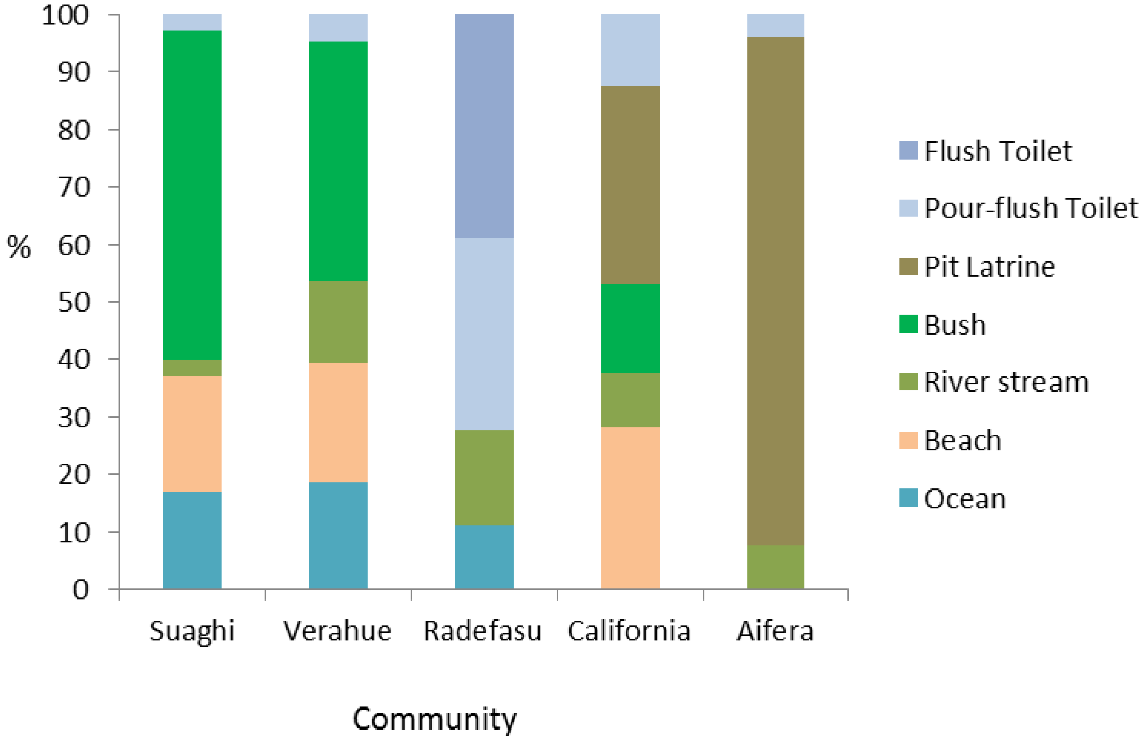

Figure 3.10. Percent frequency of sanitation practices reported in five SI communities.

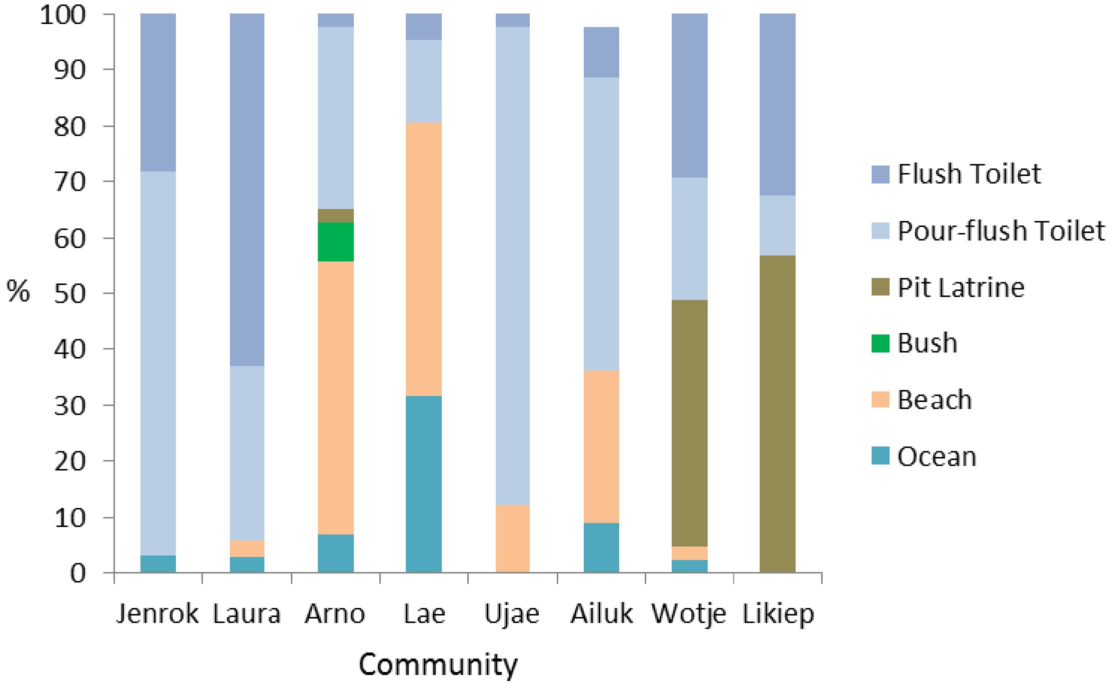

Figure 3.11. Percent frequency of sanitation practices reported in eight RMI communities.

Finding 2 – Gender and sanitation satisfaction

Improved sanitation practices were found to lead to greater gender separation in SI (Figure 3.12), but not in RMI (where sanitation is already very strongly gender separated) (Figure 3.13).

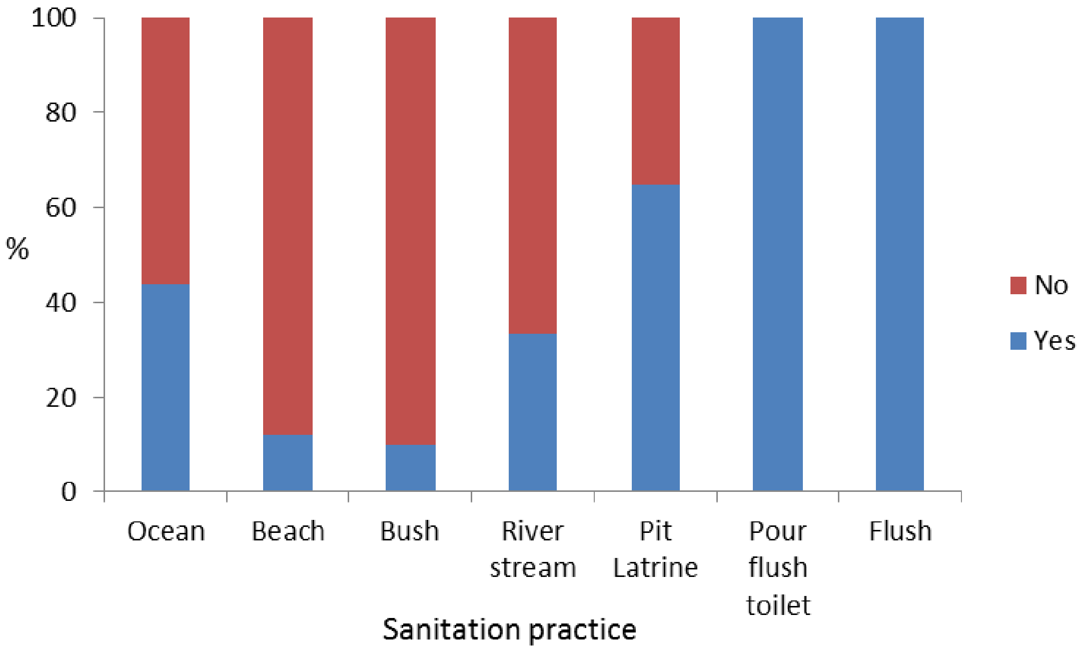

Figure 3.12. Proportion of SI respondents reporting gender separated sanitation practices, by sanitation type.

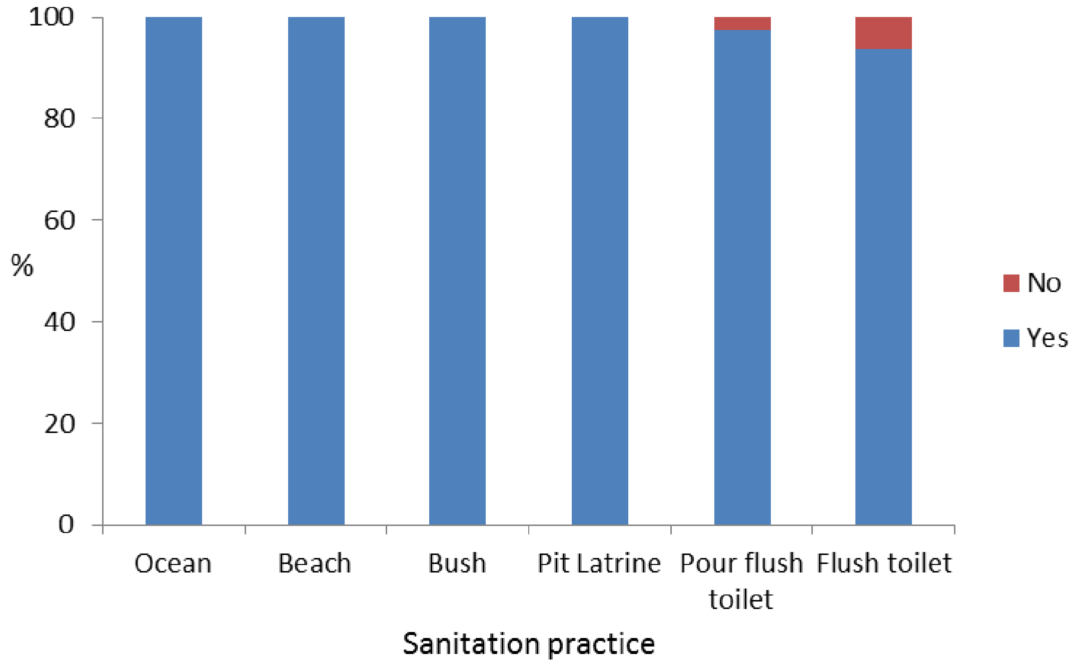

Figure 3.13. Proportion of RMI respondents reporting gender separated sanitation practices, by sanitation type.

Despite the wide range of sanitation options currently in use across all thirteen communities surveyed, respondents from all communities generally reported a relatively high level of satisfaction regarding their sanitation practices, across all types. Indeed, improved sanitation doesn't necessarily translate into improved sanitation experience. Specifically, SI respondents reported high levels of dissatisfaction around sanitation experiences for pit latrine and pour flush toilets – with much lower levels of satisfaction reported relative to those reported for OD practices (Figure 3.14). In contrast, RMI respondents tended to have a relatively high level of satisfaction regarding sanitation experience – typically with over 70% of respondents indicating satisfaction – regardless of sanitation type (Figure 3.14).

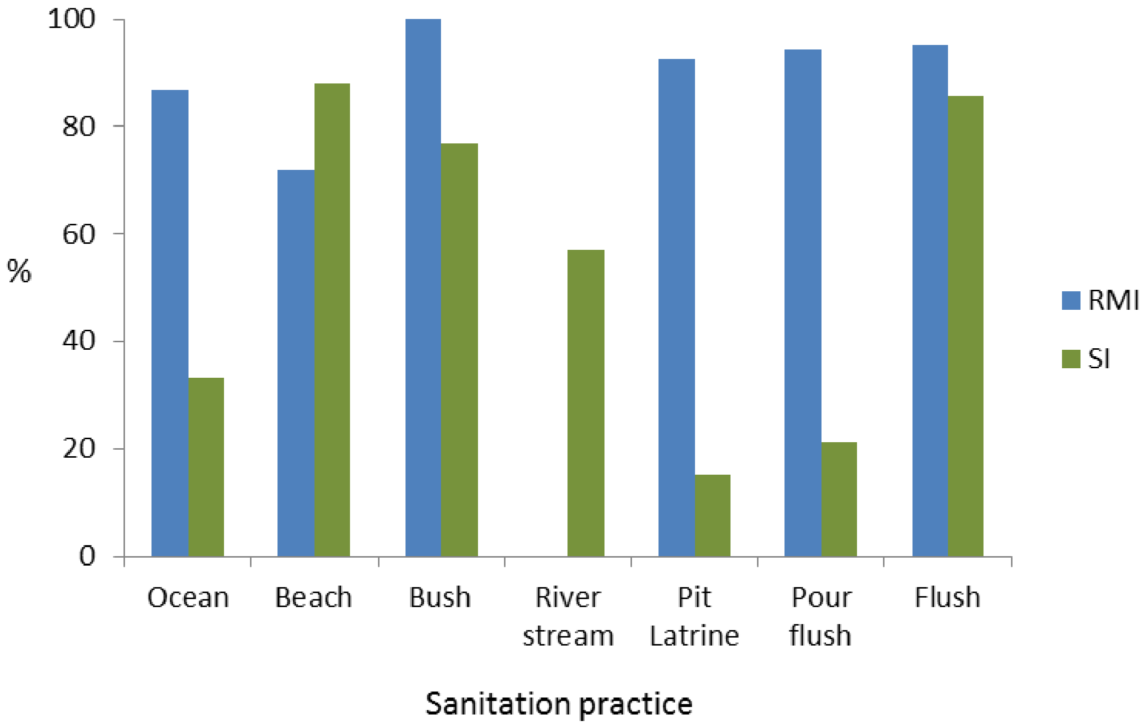

Figure 3.14. Percent of respondents reporting satisfaction with sanitation experience, by sanitation type and across RMI and SI.

Finding 3 – Sanitation service issues - maintenance and waste management

In the context of understanding the system within an IWRM framework, it is important to characterize sanitation and the management of human waste. With this in mind, respondents were asked to identify how their system was managed (and by whom) and where faecal waste goes when their system overflows. The vast majority of respondents, from both RMI and SI, indicated that they did not know if the system was maintained or who would likely be responsible for the maintenance activities (Figure 3.15). This represents a faecal waste management problem in all of the surveyed communities, especially those which have no experience in dealing with human waste given their traditional way of life.

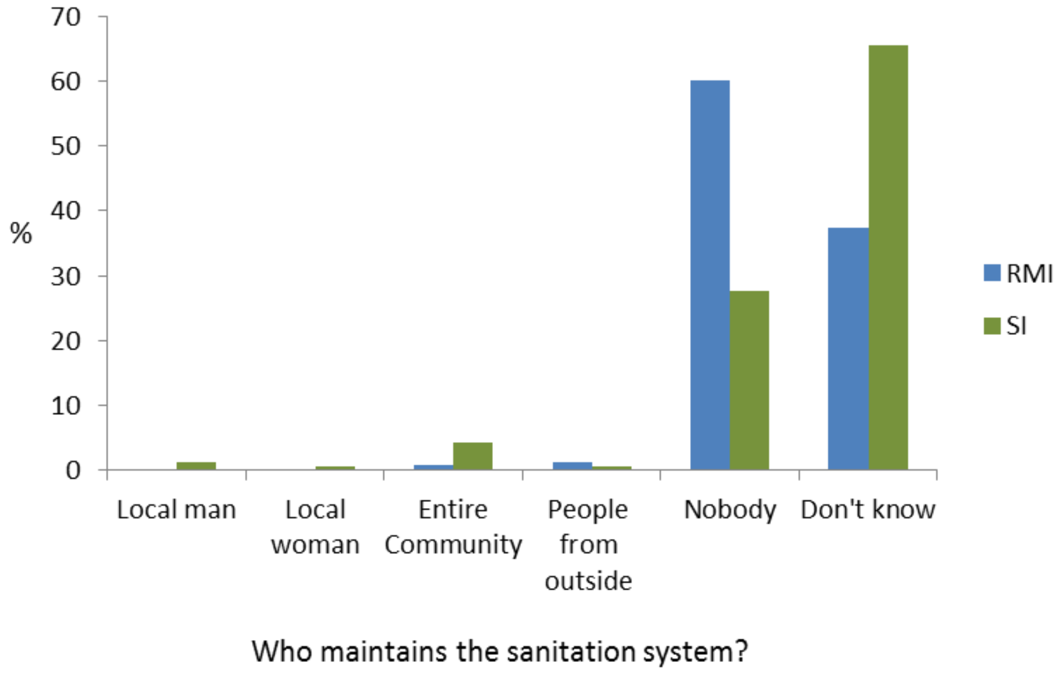

Figure 3.15. Percent of RMI and SI survey respondents reflecting on who maintains the sanitation system.

For many of the sanitation options currently in use, many people don't know where the faecal waste goes (Figure 3.16). This represents both a knowledge and understanding gap but also a significant environmental risk, as even for instances where pit latrine and septic tanks were nominated, these represent threats to the surrounding environment if and when they overflow (Figure 3.16).

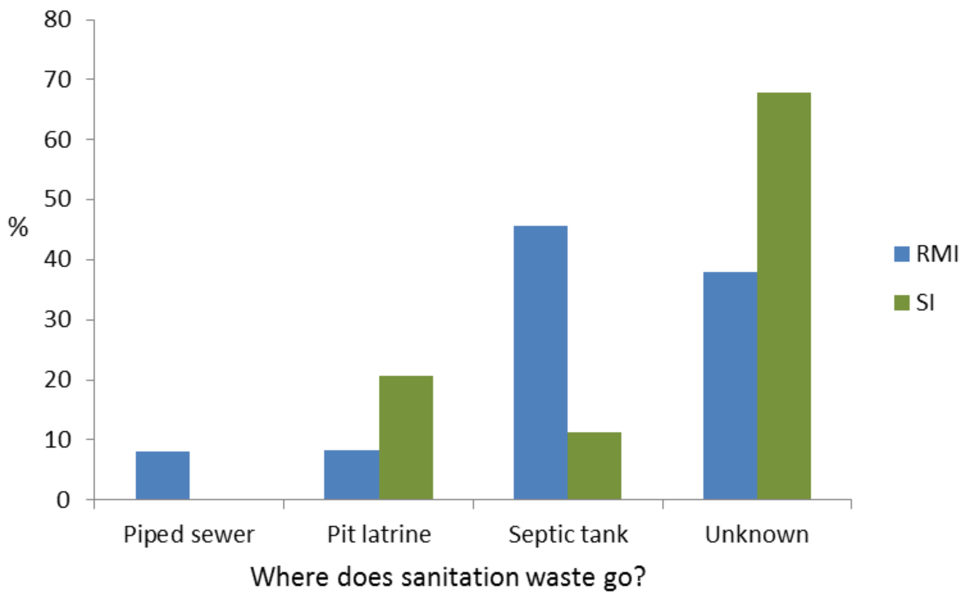

Figure 3.16. Percent of RMI and SI survey respondents reflecting on where sanitation system waste goes.

Recommendations

There remains a lot of work to do to improve sanitation services and understand why some systems are received, viewed, used and maintained more favourably than others. The research presented here also suggests significant differences between communities in RMI and SI, so understanding the local geographical and social context is critical to identifying the most appropriate sanitation options. This inevitably includes the need for a thorough understanding of the local water system and a recognition of the fact that improved sanitation services need maintenance to ensure that both human health and environmental health are not compromised.

3d. A study of extremes - Understanding patterns of water use during floods and droughts

Acute water issues, exacerbated by climate change, threaten the health and well-being of people living in Pacific Island Countries (PICs). Resource limited rural communities in the South Pacific face severe freshwater shortages caused by intensifying extreme weather events and increasingly variable seasonal rainfall. We studied water and sanitation systems in more than 100 communities in the Solomon Islands and nearly 300 in the Republic of the Marshall Islands (RMI). We developed targeted household interviews and community focus groups to examine the social and biophysical contexts of modern and traditional adaptation options designed to mitigate the effects of cyclones, floods, and droughts in coastal, floodplain, and atoll settings.

The Republic of the Marshall Islands

The threat of water shortage is always on the horizon for RMI communities, especially those living in the more remote *Outer Island* clusters. Historically, these communities have mitigated drought with their traditional knowledge, such as sourcing drinking water from coconuts, and conserving stored rainwater. However, as the water demands of communities slowly modernize and require more water, and seasonal precipitation patterns become less reliable and more unpredictable, modern technologies and adaptation measures are needed to secure water for communities throughout the year. Rainwater tanks have been extremely successful at providing year-round drinking water to households that are able to implement conservative measures and save their rainwater for consumptive needs, such as drinking and cooking, and use other less potable sources for non-consumptive needs, such as gardening, doing laundry, bathing and handwashing. Over 87% of the households we surveyed in RMI, a nation of low-lying coral atolls, reported dependence on seasonal rainfall for drinking water. During the dry season, marked by months with very little rain, the number of reported rainwater sources is largely unchanged, as depicted in Figure 3.17. During times of drought and severe water scarcity, their remain a large number of households which still depend on rainwater for drinking and cooking, reporting long term storage of rainwater in private tanks and austere usage behaviours.

In order to adapt to their changing environment and conserve rainwater for consumptive uses, such as drinking and cooking, RMI households look to other water sources to supplement their household water needs. Groundwater wells, which draw on a freshwater lens contained within the upper layers of sand of coral atolls, are commonly used to meet household water demands. Although brackish during the dry season and times of drought, well water is used to boil fish, clean the house, wash clothes, and perform personal hygiene. Often brackish, even during the wet season, well water is not generally the preferred drinking water source but is consumed out of necessity when rainwater becomes unavailable. Figure 3.18 shows how well water is preferentially used for non-consumptive uses, yet usage for consumptive purposes increases from the wet season to the dry season, and again during times of drought.

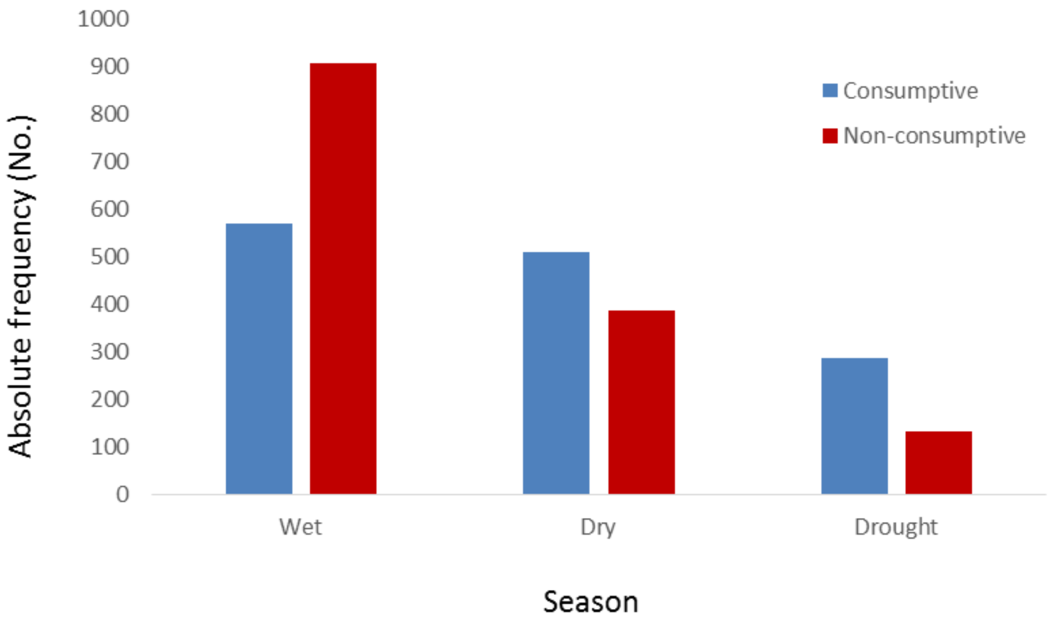

Figure 3.17: The absolute frequency of responses for both consumptive and non-consumptive uses of rainwater in RMI during wet, dry and drought periods.

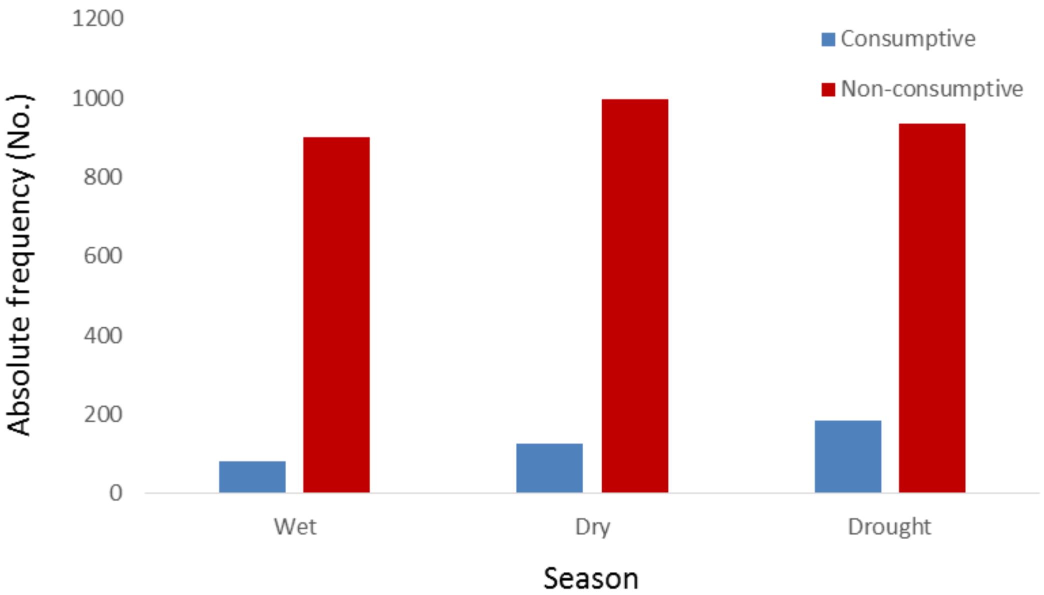

Figure 3.18: The absolute frequency of responses for both the consumptive and non-consumptive uses of well water in RMI during wet, dry and drought periods.

The urban centre and capital island of Majuro, has employed multiple high capacity RO systems in response to water shortages caused by extreme weather events. The *Majuro Water and Sewage Company* (MWSC) operates and manages these systems from central locations such as schools and community centres. Focus group discussions revealed how residents often wait in line for hours a day in order to fill their containers. Water allowances from the RO system are not strictly regulated and conflict often arises between those waiting in line. The situation is somewhat different in the outer islands of RMI where portable briefcase-sized RO units are distributed by boat, sometimes in anticipation of forecasted drought conditions and sometimes in response to emergency shortages. These solar and diesel powered systems are capable of producing a maximum of 1300 litres per day of freshwater, intended to provide for up to 400 people. Consequently, not everyone has access to RO-produced water, and most households are required to supplement their use of RO water with well water.

The provision of RO units to outer island communities has likely saved lives and proven itself to be an essential tool in drought response. However, the adoption of this technology has created tension between communities that now request RO units during dry, albeit non-emergency conditions and the government who reserves these units for times of crises. The MWSC has had difficulty reclaiming the portable ROs for regular maintenance from outer island leaders who do not wish to part with such valuable machines, and who may not fully understand the necessity of the maintenance to be done. There are also issues of installation and the selection of the water source to be filtered. A senior MWSC official explained during an interview that only brackish well water is to be filtered, but evidence from focus groups suggests that some outer island community leaders have ordered the water source changed. Excessive harvesting of high-quality well water can deplete the freshwater lens and make it more vulnerable to saltwater intrusion. Compromising the lens greatly decreases the community's resilience to drought should the RO unit malfunction. In effect, some of the applications of RO in remote communities increases the risks of drought-related health problems. Coupled with the loss of traditional practices and behaviours around water-sharing and conservation, the inappropriate application of a new technology like RO might, in the long-term, effectively reduce community resilience to climate change impacts. Increased attention to the social and biophysical contexts and integrating traditional and modern adaptation approaches will provide vulnerable communities with the tools and capacity to withstand future drought events.

Solomon Islands

Similar adaptive capacity is found in SI, a country with routine experience of high magnitude tropical storms and devastating floods. The challenge for many rural communities is, therefore, not in finding freshwater, but finding water that is free of pathogens and safe for human consumption. During heavy rainfall events, wells and surface water bodies are inundated by flood waters that contain debris and biological contaminants, including human faeces that can accumulate from open defecation. Significantly, despite the fact that 79.1% of households felt that their drinking water was unsafe to drink, only 13.4% reported using any kind of treatment. During floods, wells are commonly inundated with contaminated flood waters, and the number of households using these wells decreases (Figure 3.19).

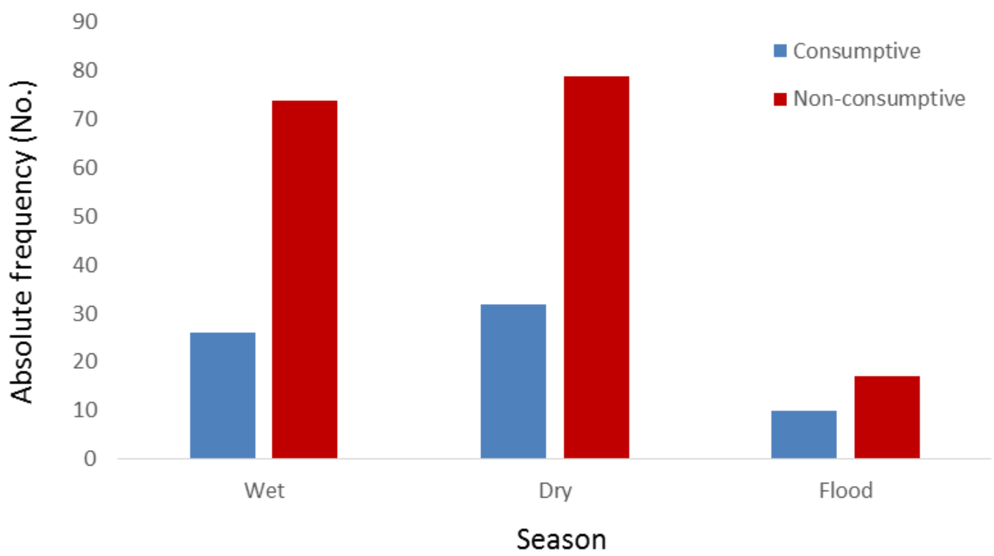

Figure 3.19: The absolute frequency of responses for both consumptive and non-consumptive uses of well water in SI, through wet, dry and flood periods.

When well water is unavailable, the proportion of households drinking rainwater increased from 43% under normal wet season conditions to 66% during floods (Figure 3.20).

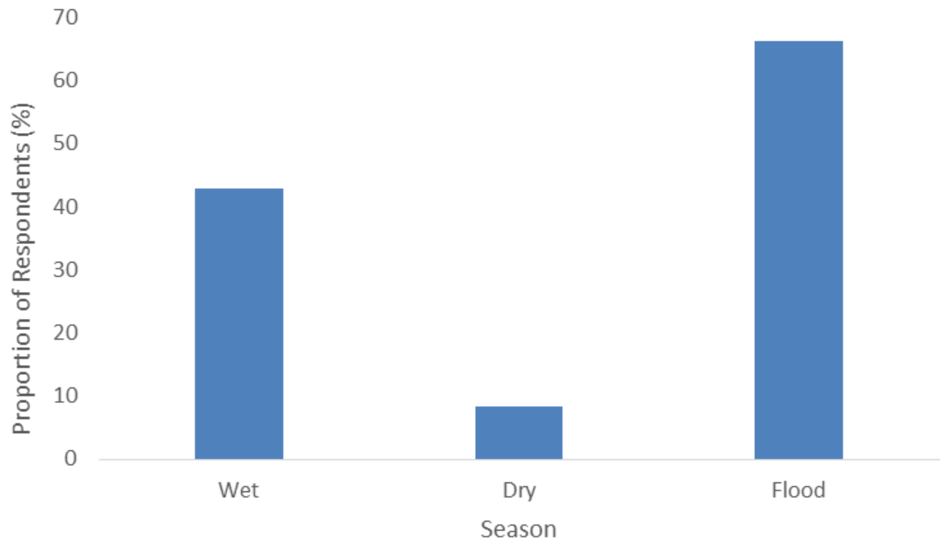

Figure 3.20: The proportion of household responses that indicate the drinking of rainwater in SI, through wet, dry and flood periods.

With greater consumption of rainwater during the wet season and floods, there is an equivalent reduction in the number of households drinking from rivers and natural springs. When rivers flood their banks they also present a physical danger of drowning, and Solomon Islanders commonly do not fetch water from them for either consumptive or non-consumptive uses (Figure 3.21). This systematic cycling of water sources and practices according to season and climate-related hazards is a form of local adaptation. Rural communities in SI have learned to cope with climate disasters and harsh environmental conditions by optimizing available water resources.

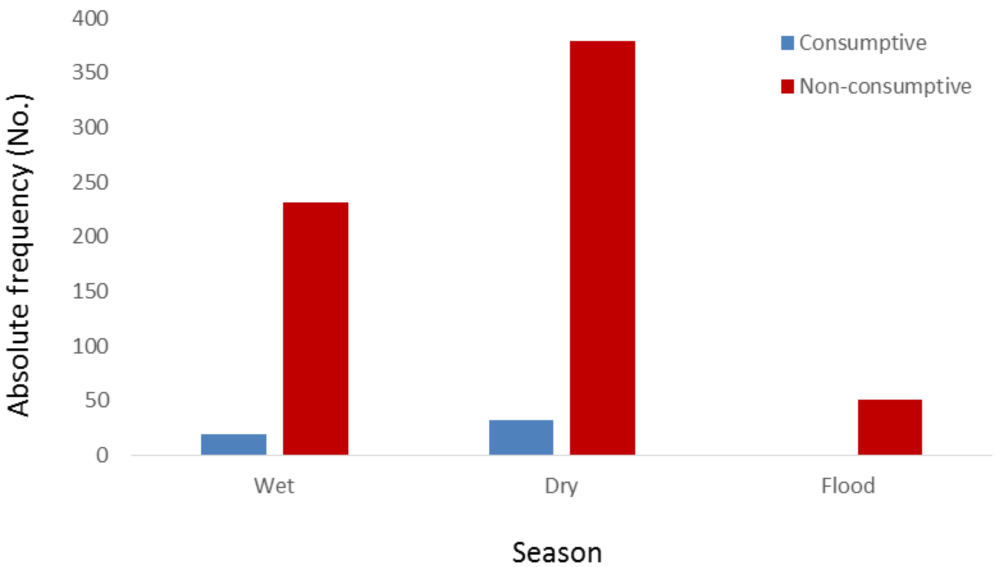

Figure 3.21: The absolute frequency of responses for both consumptive and non-consumptive uses of river water in SI.

Climate change adaptation in the Pacific is evolving as the confluence of traditional knowledge and contemporary technology. The ancient knowledge of village elders has transcended generations of Islanders, with teachings of disaster response and freshwater conservation. Modern adaptation options including donor funded treatment technologies, such as reverse osmosis for the desalination of brackish water, are comparatively new to PICs, with unknown long-term impacts with respect to community-level resilience. Our evaluation of the impacts of extreme weather events in rural Pacific Island communities, along with local adaptation used to mitigate the effects of climate change, and the need to integrate traditional and modern knowledge can be used to inform future decision making in order to strengthen community resilience in light of climate threats.

Section 4: Decision-support models to understand WaSH interventions and climate change risks

Background

Uncertainty and concern over the impacts of climate change are drawing attention to water resources and their management in the Pacific Islands, particularly given the water-based extreme events including floods, cyclones, storm surge and drought in recent years (Hadwen et al. 2015). There are multiple hazards faced by local communities associated with water and sanitation, and the impacts of these are likely to be exacerbated by anticipated changes to climate, weather and development. Analysis of these impacts, risks, and determination of possible strategies for adaptation and mitigation is urgent. The development of robust models, which can handle the high degree of uncertainty and risk associated with data-scarcity, are essential tools that will aid in the decision making around WaSH interventions and climate change adaptation options.

Models are simplifications of complex systems that help us understand how they work. For the complex WaSH settings in remote and rural communities throughout the Pacific, decisions around interventions and climate change impacts lend themselves to evaluation through models. However, many modelling approaches require high quantities of high quality data as input, and this is a problem in many parts of the Pacific, where historic and current data collection is inconsistent, scattered, sparse or entirely lacking. To address the data scarcity problem, in addition to the household level surveys described in Section 3, we used participatory processes that encouraged local development through collaboration and information sharing, and which also provided ways of filling in knowledge gaps around the local physical and social environments as well as around water and sanitation management and decision-making. Here we use our own expertise and understanding of integrated water resource systems around the world, as well as the information sourced directly from local communities in RMI and SI through surveys and focus group discussions, to build a systematic understanding of water and sanitation at the community scale. We then used this data to build a series of Bayesian Belief Network (BBN) models – see below for the methodological details.

In general terms BBNs are incredibly useful models for aiding decision makers, due to their capacity to support scenario testing (Phan et al. 2016). Our BBNs, detailed below, have been built from HH level data and can be interrogated to evaluate intervention and adaptation options for a) individual communities, b) zones or provinces, or c) an aggregated country scale. In addition, the BBNs assess base case scenarios as well as those represented by extreme events like floods, droughts and cyclones, all of which are anticipated to become more frequent and more intense as a result of climate change. To best represent the settings and recognise the differences between flood prone and drought prone communities in the Pacific region we have developed two separate BBNs – one for RMI and one for SI. This also enables us to evaluate the differences between different countries and to focus on regionally relevant climate threats to identify the most relevant possible adaptation options. In terms of scenario testing, the BBNs can help us visualise the effects of different climate impacts and, in turn, evaluate the likely outcomes and efficacy of different adaptation options. The need to evaluate options prior to implementation is highlighted by the fact that current decision making is informed by incomplete or outdated information and this can have significant negative downstream effects including maladaptation (causing additional problems), inappropriate spending and misallocation of resources and lack of community acceptance and maintenance of the delivered services (Clarke et al. 2014).

4a. An introduction to BBNs

Computer models are one way to represent and simplify the interactions that control real world systems and to help us understand how they work. Their ability to automate calculation of quantities facilitates provision of information to support decision-making around interventions to complex systems such as WaSH/watsan.

Bayesian Networks are one kind of computer model with some advantages over other approaches. They are sometimes called Bayesian Belief Networks (BBNs) to be explicit about all models relying on assumptions and beliefs, and also because of their ability to specifically include beliefs about a system (e.g. from experts, including laypersons or stakeholders, who have experience with a system) in the place of measured data (e.g. where it is not available because the data would be expensive or difficult to collect, or because a system is little studied) – this is often not possible in other modelling approaches.

BBNs get their name from Reverend Thomas Bayes who developed a mathematical formula for calculating probabilities (published posthumously in 1763) amongst related variables for which the relationships are not known (see the "Infobox: Bayes Theorem" for more details).

> Infobox: Bayes Theorem
>
> The networks rely on a relationship developed by Bayes. In probability notation, for two events A and B:
>
> $p(A|B) = p(B|A) \times p(A) / p(B)$
>
> This says that if we have a high degree of belief in the likelihood of event A occurring based on past experience (i.e. the probability of A, p(A), is high), and we now observe data for Event B (i.e. the probability of B, p(B), and also the probability of B ***given*** the we have also observed event A, p(B|A)), then our "after the evidence confidence" (i.e. probability of A ***given*** the probability of B, p(A|B)) should be strengthened. This is "inference", which allows us to determine which "cause" can "explain" observed data better. Although calculating these probabilities is simple for the case of A and B only, it quickly becomes complicated when we have additional variables C, D, E, etc., with multiple connections and with increasing pieces of observed data.

BBNs have only recently had practical application with the development of computer hardware and software that can calculate these Bayesian relationships among a useful number of variables. As an example, Microsoft Office now uses Bayesian Networks to decide how to offer users help, based on past experience with the user. Bayesian Networks are now increasingly being applied to medicine (e.g. diagnoses), engineering (e.g. process engineering) and the environment (e.g. fisheries) among many areas/situations.

How does a Bayesian Network work?

A Bayesian Network is a diagram of system variables, for example, factors such as use of rainwater, well water, river water and spring water if a network is looking at drinking water. Links between the variables represent the cause-effect relationships between them (for example, a link between whether rainwater is used and drinking water). The relationship between variables can be defined by data directly (using Bayes' Theorem), or by a specified mathematical relationship (as in traditional deterministic computer models) or be quantified with a set of expert/stakeholder/etc., belief-defined probabilities (so-called "Conditional Probability Tables") specifying the belief that a variable will be in a particular state (e.g. enough drinking water) given the states of the variables that affect it (e.g. rainwater is used). The network uses these defined relationships to calculate how much and in what way each part of a system affects the others. BBNs attempt to give a useful estimate of a predicted outcome (for example, whether drinking water is available given certain environmental or behavioural conditions) even if apparently key pieces of information are poorly known. Thus the value (or "state") of a node is a result of the states of the nodes linked to it. The network can then be "trained" with data. The more evidence there is on how the system has behaved in the past, the more certain we can be that it will behave in a similar way in the future.

Inputs to a Bayesian Network can include and combine data from regular monitoring (e.g. for water quality, weather stations), from specific studies or surveys (e.g. once-off fauna surveys). Sometimes no data is available for a certain variable because it is complicated or expensive to collect, or because the region under consideration is remote or inaccessible, or because no one has previously been interested in that type of data or that region. If no data is available, consultation with experts to obtain their opinion on nodes/relationships can be used until data can be collected, with predictions based on this having a higher uncertainty than those predictions based on measured data.

The output from a Bayesian Network can be a prediction on the state of the measurement endpoint, for example "good", "moderate" or "poor" abundance of a certain focal species. This output can be compared for different management actions to assist in deciding whether an action is worth taking, or which action is most likely to give the best result.

BBN purposes and uses

Bayesian Networks can be useful tools for understanding how management decisions can affect a system. They are particularly useful where there are many possible management actions, and many criteria on which to base decisions about which are the best management actions. They can also be used to increase our understanding of the relationships between components making up a system. Because they are graphical, BBNs can also improve communication, for example between stakeholders with different areas of experience, and also facilitates input from people less familiar with computer modelling, but with a good understanding of the system.

Bayesian Networks are particularly useful where a relationship between variables is thought to be important but where our understanding of that relationship is incomplete. In such situations we need to describe the probability that particular relationships will occur, based on our observations of the variables.

One of the most important features of Bayesian Networks is the fact that they can account for uncertainty. This is particularly important given the complexity of the natural world and the difficulty in making exact predictions of the effects of management actions. Managers need to balance the desirability of an outcome against the chance that particular management actions may not lead to the expected outcome. Additionally, Bayesian networks are easy to adapt and change as our understanding of the system develops, if new factors come into play, or when new data is collected. The network can “learn” from additional data and become better at predicting outcomes.

Methods - BBN development of floodplain and atoll models

Participatory processes and guided discussions were used with gender and age diverse stakeholders in Pacific floodplain and atoll communities, one-on-one and in groups, to elicit what they prioritised for management and the local factors (variables) affecting water and sanitation, including threats, hazards and other issues. All communities involved were most concerned with whether they would have enough drinking water of adequate quality, and this has been used as the focus (endpoint) for both the floodplain and atoll BBNs.

Eliciting and understanding the perspective of the local stakeholders (e.g. customary landowners) is essential to a balanced and nuanced understanding the water and sanitation systems they use. Participatory processes also provide opportunities for co-learning and knowledge exchange between stakeholders (e.g. Figure 4.3).

Participatory conceptual mapping exercises were further used with community stakeholders to draw out key cause-effect relationships of concern (e.g. Figure 4.4 and Figure 4.5). Stakeholder participation and input improves the systems analysis and enhances uptake of resulting decisions by ensuring local knowledge is included and concerns are addressed.

Figure 4.3. Community stakeholder group participating in conceptual mapping exercise.

Figure 4.4. A conceptual diagram (water supply hazards) developed by community members via participatory exercises.

Figure 4.5. A conceptual diagram (sanitation issues) developed by community members via participatory exercises.

The community outputs were compiled by the researchers, based on their expertise in integrated water resource management, into an overall conceptual diagram describing the key aspects of water and sanitation affecting drinking water in the two types of communities (floodplains and atolls). Figure 6.4 and Figure 4.7 show the conceptual diagrams for the floodplain and atoll cases.

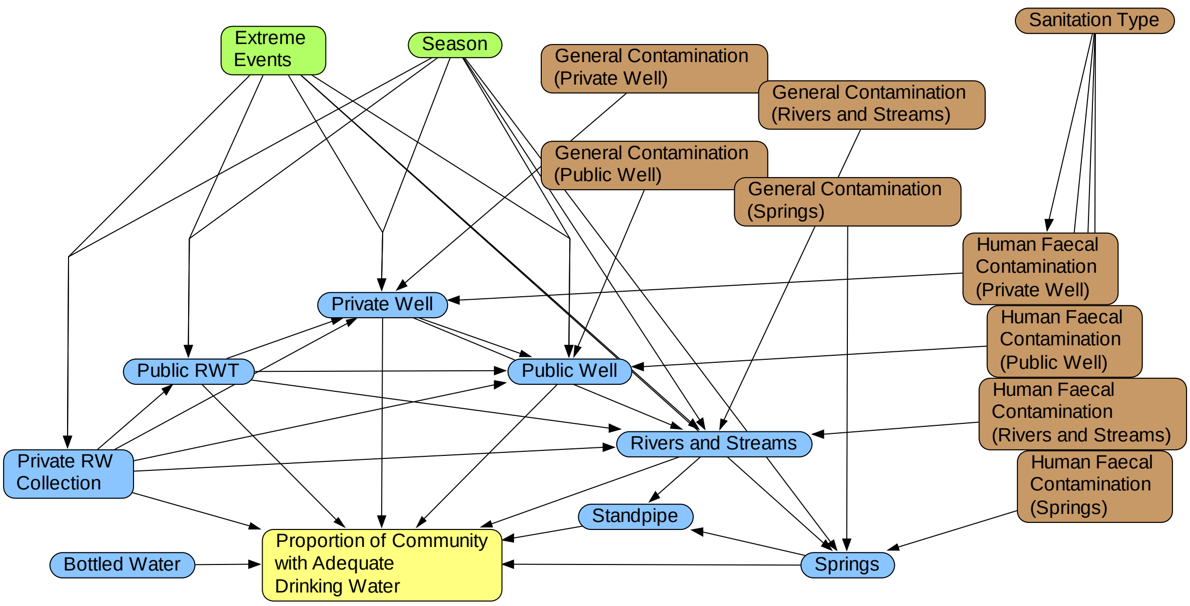

Figure 6.4. Conceptual diagram for drinking water in floodplain communities, including multiple water sources and impacts from sanitation. Note this Figure omits location variables (community and region) for simplicity.

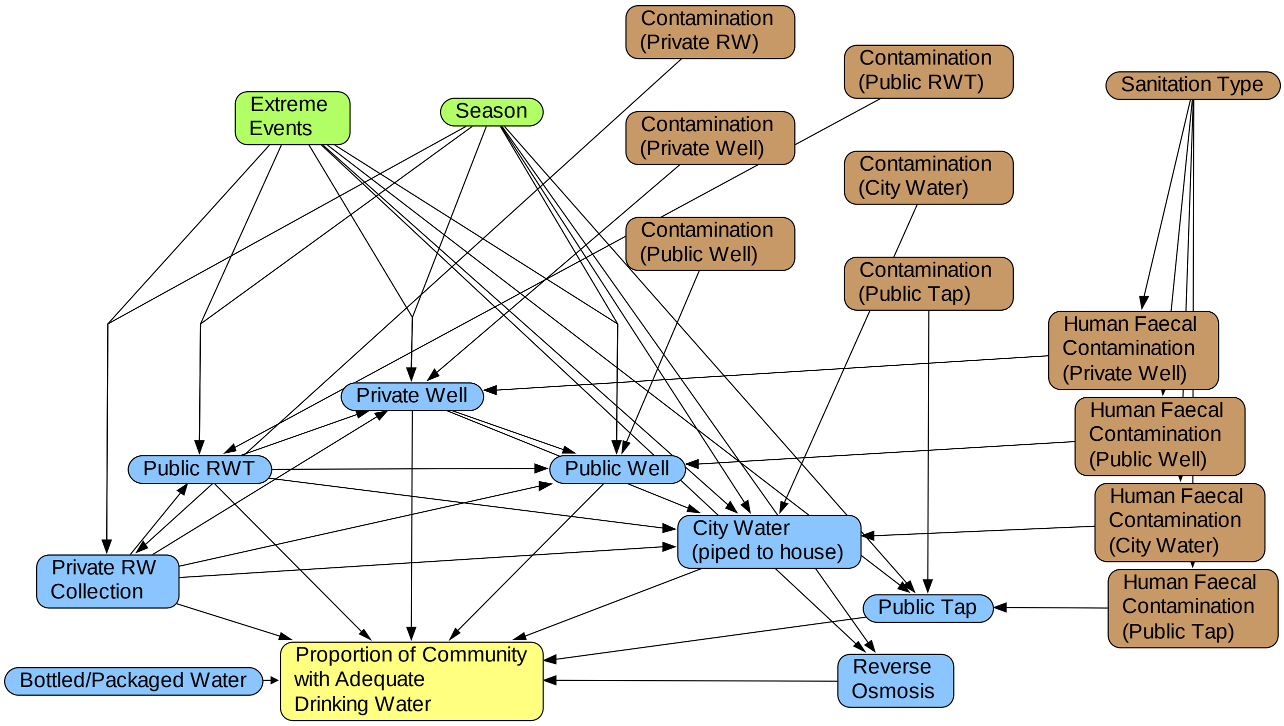

Figure 4.7. Conceptual diagram for drinking water in atoll communities, including multiple water sources and impacts from sanitation. Note this Figure omits location variables (community and region) for simplicity.

The conceptual diagrams were then used to develop quantitative BBNs by using the household survey data collected from the five floodplain and eight atoll Pacific communities as described in Section 3. In the drought-prone atoll country of RMI we carried out 299 household interviews across eight communities. In SI, we conducted 106 household interviews across five flood-prone communities.

This quantitative data was used to define how variable relationships change, using (Reverend Thomas) Bayes' probabilistic theorem (see Infobox) that allows use of whatever quantitative information is available to calculate the likelihood that a certain variable will behave in a certain way, given what the way the variables linked to it are behaving. The more evidence there is on how the system has behaved in the past, the more certain the BBN will be that it will behave in a similar way in the future. This probabilistic method explicitly accounts for uncertainty, which is useful given the complexity of the natural world and the difficulty in making exact/deterministic predictions of the effects of management actions. Decision-makers (e.g. managers and policy makers) need to use this type of risk-based approach to balance the desirability of an outcome against the probability that a particular management action may not lead to the planned outcome. The base quantified BBNs for floodplains and atolls are shown in Figure 4.8 and Figure.

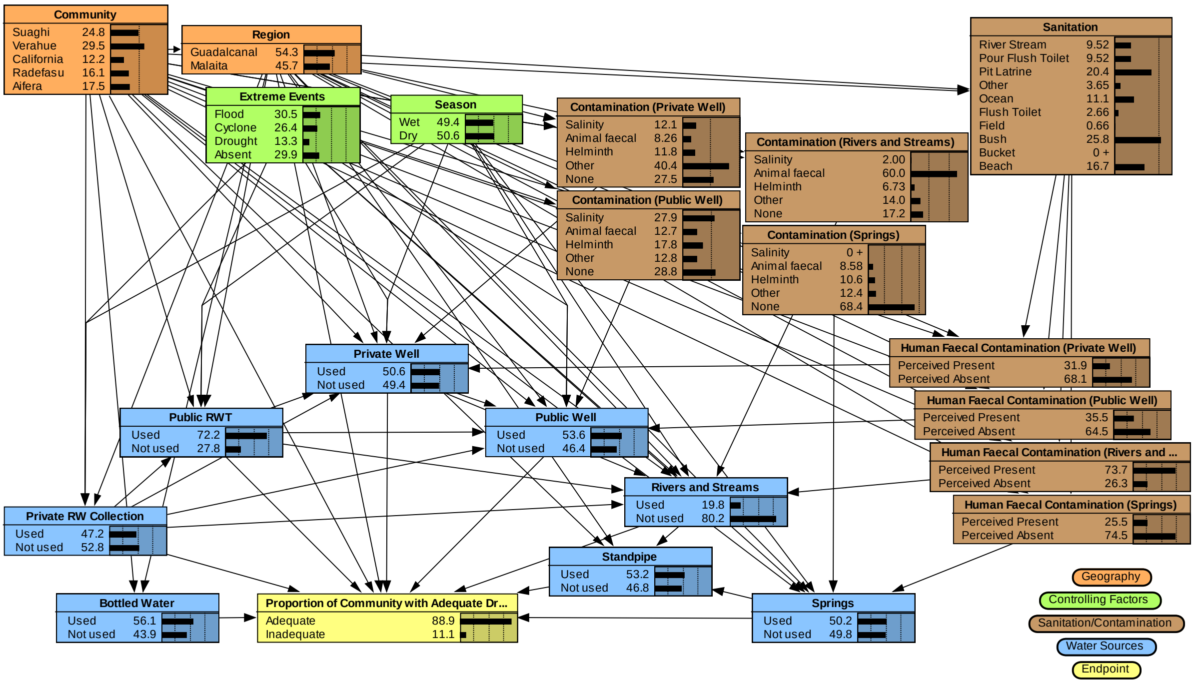

Figure 4.8. Floodplain model with survey data incorporated to define quantitative relationships.

A measure of model validation is shown for the floodplain BBN in Table 4.1 and the atoll BBN in Table 4.2. These "confusion matrices" compare predicted (modelled) to actual (measured) outcomes for the drinking water endpoint. The analyses used a randomly selected set of the survey dataset which was reserved and not used in training the models. Relatively low error rates of 2-7% indicate high model reliability. The lower rate for the atoll model indicates higher certainty, possibly because of more homogenous data (e.g. the atoll communities informing this model may behave more similarly than the floodplain communities).

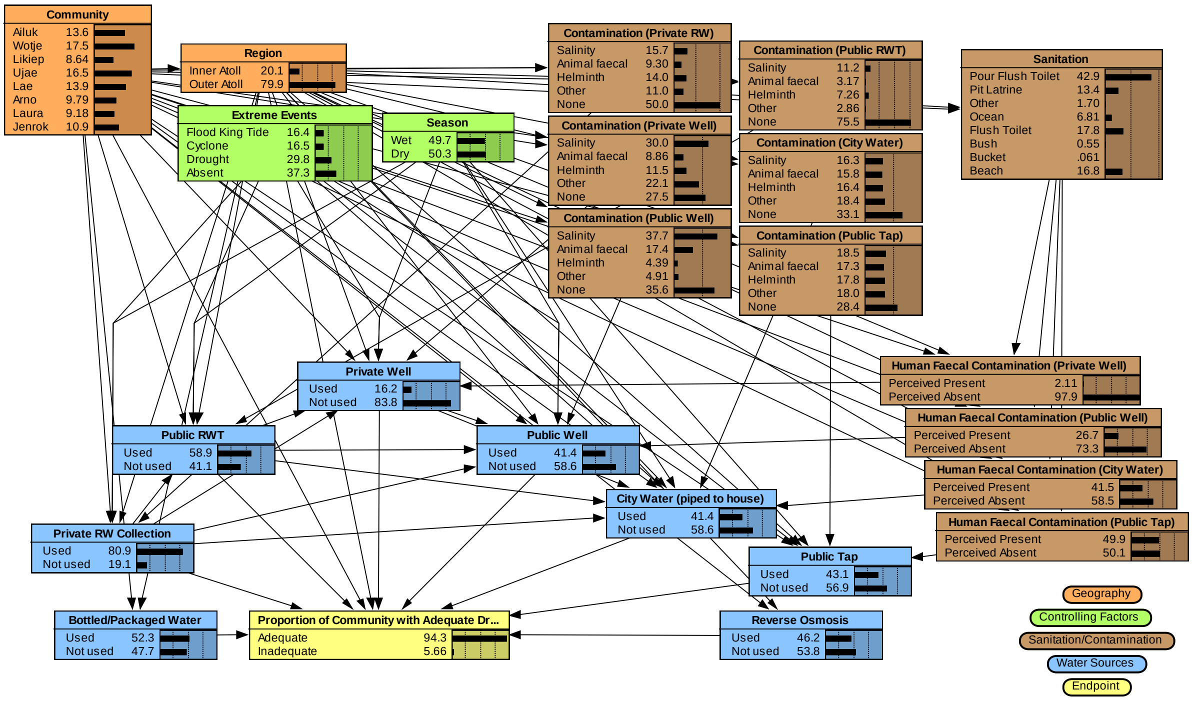

Figure 4.7. Atoll model with survey data incorporated to define quantitative relationships.

Table 4.1. Floodplain BBN confusion matrix (validation against randomised reserved 25% of dataset. Error rate ~7%.)

Adequate	Inadequate	Actual
256	4	Adequate
19	22	Inadequate

Table 4.2. Atoll BBN confusion matrix (validation against randomised reserved 25% of dataset. Error rate ~2.7%.)

Adequate	Inadequate	Actual
526	3	Adequate
12	7	Inadequate

Using the BBN model to examine scenarios

The finalised BBNs can be used to examine different scenarios, e.g. climate scenarios, intervention options, or changes in behaviour, and to examine what the likely outcomes might be at various parts of the system. Critically, because the BBN is built on data collected across a range of different, yet representative communities, there is scope and capacity to use the BBN models to evaluate a) community level impacts and interventions, b) provincial scale impacts and interventions, and c) whole-of-country level impacts and interventions. The utility of this scaled approach to understanding impacts, interventions and their outcomes is highlighted by examples which show how different community settings can result in different outcomes. This is critically important throughout the Pacific Region, as community size, structure, traditions and culture ultimately play a very strong role in determining the success, or otherwise, of WaSH service implementation activities. As an example using the BBNs created for the floodplain communities, Figure 4.9 shows an example of how the proportion of the community with adequate drinking water changes across five different scenarios illustrated for two SI provinces.

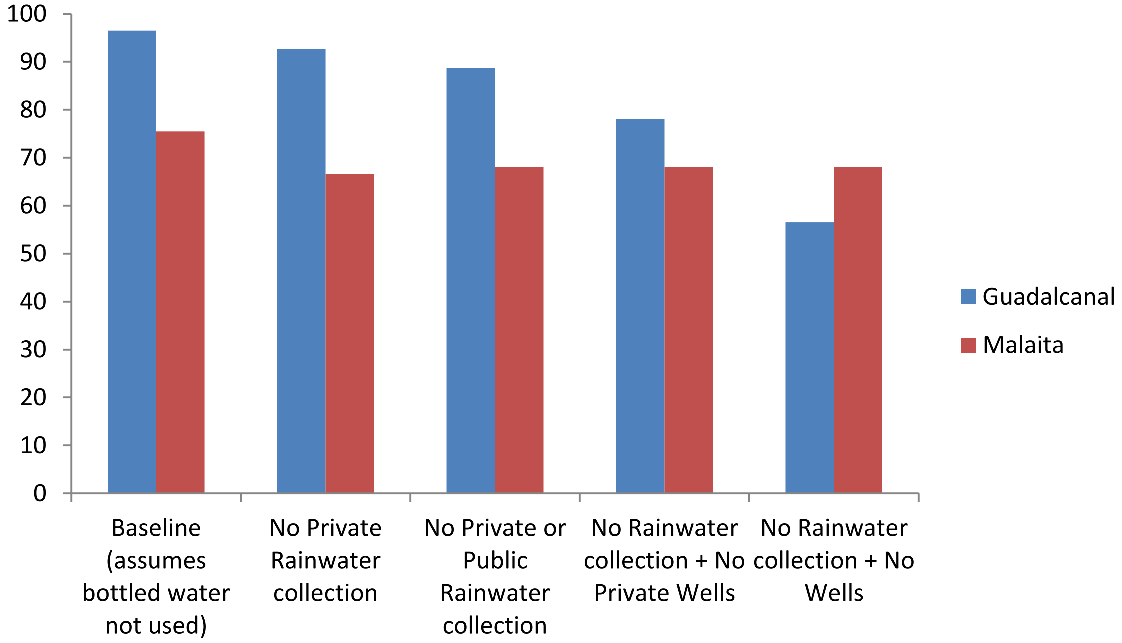

Figure 4.9. Comparison of scenarios for "Proportion (%) of Community with Adequate Drinking Water" for communities in different regions of SI

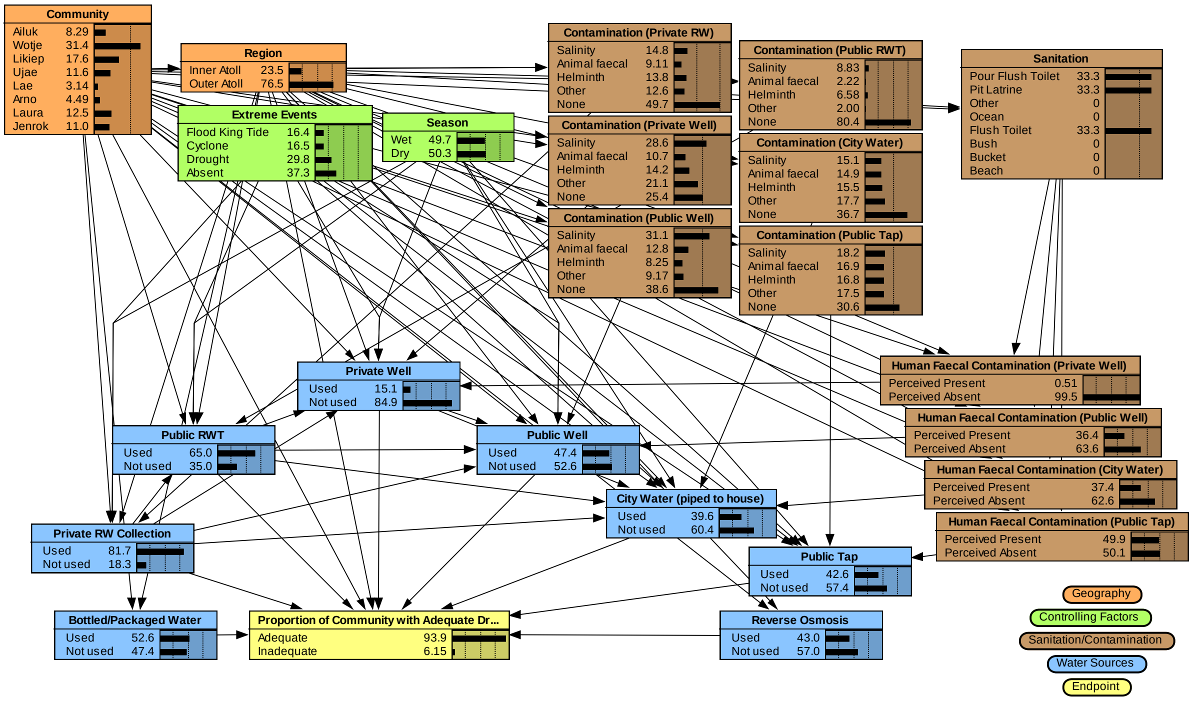

Figure 4.10. Atoll BBN: looking at impact of "improved" sanitation options.

As different water sources are removed from use (e.g. if rainfall is not collected at a private/household or public/community level or if wells become unusable), how is drinking water affected? How is this different for communities in different provinces? These scenarios and outputs provide decision support around water and sanitation interventions, management and policy development. The next two parts of this section will focus on applications of the SI and RMI BBNs, to draw out management recommendations in light of the current WaSH settings and the likely climate impacts that will variously impact on flood prone communities (like those in the Solomon Islands) and drought prone atoll communities (like those in the Marshall Islands).

4b. Application of the BBN - Improving water supply in rural communities via better use of rainwater tanks in the Solomon Islands

Background

RWT implementation and sustained use are a key focus of many government and non-government organisations looking to increase water security for rural communities in the Pacific. However rainwater use (including both private/household and public/communal level collection) are only part of a mix of sources used under a range of conditions.

Figure 4.11. Partly functional communal rainwater tank (no tap) in Suaghi village, Guadalcanal, Solomon islands.

A Bayesian Belief Network model was developed using primary data collected from five communities in flood-prone areas of the Solomon Islands. A number of scenarios were analysed leading to the findings below.

Finding 1: Current use of RWH

Rainwater tends to be overall preferred for drinking but a number of conditions determine whether it is used or not, including season, the presence or absence of an extreme event and its type (i.e. flooding, drought or cyclone), the availability of other sources (e.g. wells), and community perceptions of contamination about each source.

Use of both private and public RWTs increases under Flood and Cyclone conditions – both in response to the availability or rainwater as well as the negative consequences that flooding has with respect to the water quality and accessibility of wells and rivers/streams. However, use of rainwater does not entirely make up the shortfall – as a result, the overall proportion of the community with adequate drinking water decreases.

The number of households using rainwater decreases during droughts, as may be expected due to lack of rain. The shortfall is largely met by increased use of other sources (e.g. wells and rivers) which persist unless a drought is particularly long.

Note this increased use occurs despite concern over increased contamination of these persistent sources at these times. Significantly, the provincial analysis undertaken here highlights Malaita's lower current/baseline use of private RWTs (38% compared to Guadalcanal's 55%) and this may represent a development opportunity in that province as it may be relatively easy for external actors to provide basic RWH support, including tanks or education where this is currently less available, and have a higher, more immediate impact on the provision of adequate quality drinking water to remote communities.

Finding 2: Impact of interventions on RWH

A formal sensitivity analysis of the floodplain BBN provided a ranking of the variables with the most influence on the management endpoint of proportion of community with adequate drinking water (Table 4.3). Use of privately (household) collected rainwater was the most influential factor, followed by standpipes (which are not an option in many rural communities) and then public/communal rainwater collection. Other factors including other water sources and perceived contamination of any source were all less influential.

Table 4.3. Floodplain BBN sensitivity analysis: : sensitivity of endpoint variable (proportion of community with adequate drinking water) to findings at other variables. Ranking lists most influential down to least influential variables.

Variables	Measures of sensitivity		
	Mutual Information	Percent	Variance of beliefs
[Drinking water endpoint]	*0.50164*	*100*	*0.0983473*
Community	0.07318	14.6	0.0115449
Sanitation	0.05127	10.2	0.0082626
Region	0.04415	8.8	0.0057743
Private RW Collection	0.0326	6.5	0.0041018
Standpipe	0.02607	5.2	0.003469
Public RWT	0.02144	4.27	0.0032236
Contamination (Private Wells)	0.01477	2.94	0.0020648
Contamination (Springs)	0.01394	2.78	0.0014831
Extreme Events	0.01154	2.3	0.0015173
Contamination (Rivers/Streams)	0.00993	1.98	0.0017049
Springs	0.00642	1.28	0.0008668
Public Well	0.00412	0.821	0.0005628
Private Well	0.00154	0.308	0.0002103
Human Faecal Contamination (Private Wells)	0.00102	0.203	0.0001415
Contamination (Public Wells)	0.00061	0.122	0.0000848
Human Faecal Contamination (Rivers/Streams)	0.00046	0.0921	0.0000614
Human Faecal Contamination (Private Wells)	0.00044	0.0885	0.0000595
Human Faecal Contamination (Springs)	0.00022	0.0429	0.0000298
Season	0.00001	0.00186	0.0000013
Rivers and Streams	0.00001	0.00137	0.0000009
Bottled Water	0	9.06E-05	0.0000001

The impact of RWH is more simply illustrated in a comparison of scenarios for improving rainwater use in Figure 4.12 and as an individual scenario in Figure 4.13 (corresponding to the rightmost blue bar in Figure 4.12). Despite rainwater use during Flood and Cyclone being higher than during baseline conditions, further improvements in both private and public rainwater use under these conditions still benefits community water supply further (see green bars in Figure 4.12). Anecdotally, RWT failure during these conditions occurs because of hardware failure such as damage to roofs, piping, and tank frame/structure.

Changing the baseline use of private rainwater collection (currently used 47% of the time) and public/communal rainwater collection (currently used 72% of the time), to "always used" could improve the endpoint adequate drinking water from a likelihood of 89% to 98%. Improving RWT use to a perfect 100% use is unlikely to be practical, and increasing effort/resources in doing so are likely to be met with exponentially decreasing improvement. However given patchy historic support of hardware (e.g. uncoordinated provision of RWT from a range of actors, but limited provision of necessary parts, e.g. piping, both in the first instance as well as for replacement) and almost total absence of software support (e.g. in operation and maintenance, social arrangements for management) for RWT use from external actors, any informed increase in support will be beneficial.

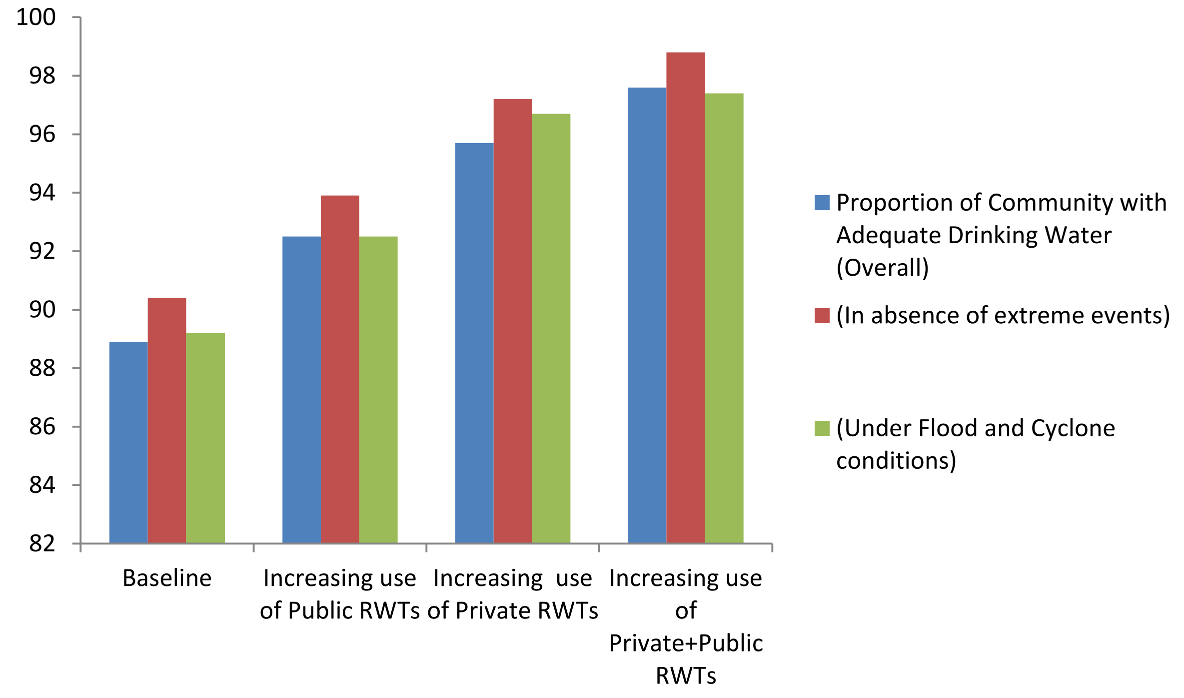

Figure 4.12. Floodplain BBN in SI: Improving use of rainwater collection.

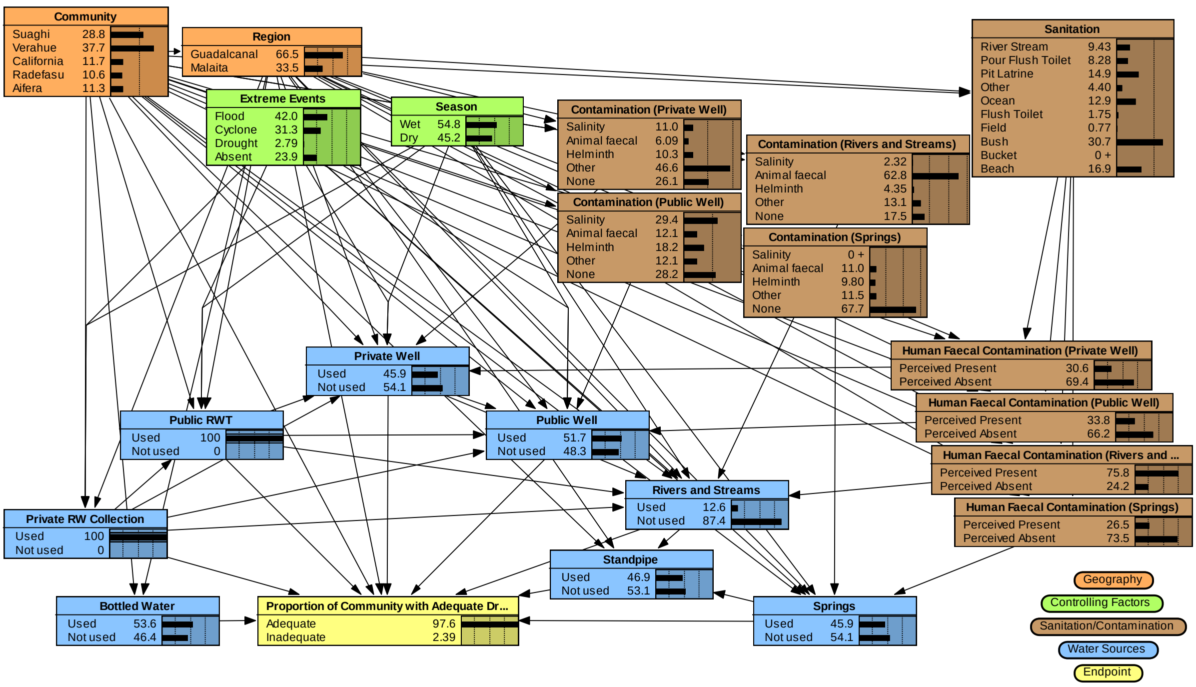

Figure 4.13. Floodplain BBN: With reliable use of RWTs.

Main findings & recommendations

Rainwater use is complex, with both private household and public/communal RWH used in Solomon Islands communities as part of a mix of up to five drinking water sources for each household. Rainwater tends to be preferred for drinking, but a number of conditions determine whether it is used. Understanding how rainwater fits into local community behaviour and reasons behind patterns of use are needed for successful assistance to communities.

Recommendation: A quantitative model can assist in simplifying and understanding the complexities around multiple sources and the factors influencing how they are used.

Sensitivity and scenario analysis of a quantitative Bayesian Belief Network model of flood-prone communities in the Solomon Islands indicates that the proportion of any community with adequate drinking water is most highly influenced by use of private (first) and public rainwater (second) collection.

Recommendation: Enhance community use of rainwater by increasing availability and sustainable use of rainwater tanks, at both household and communal community level, including provision of hardware, and/or incentives for maintenance and damage repair.

4c. Application of the BBN – Understanding and mitigating the impact of drought in the Marshall Islands

Background

The communities in RMI are prone to a range of climate-related threats, ranging from storm surge and saline intrusion, to the impacts of severe drought. During the life of this project, RMI has suffered through several severe droughts. To address the challenges associated with drought and WaSH in RMI communities, we used the BBN model described earlier, built using primary data collected from eight communities in drought-prone atoll communities of RMI, to assess a number of scenarios relating to drought response and water management.

Findings 1: Current use of rainwater harvesting (RWH) and reverse osmosis (RO)

It should first be noted that although this research has been conducted in these communities on the basis that they are drought-prone, they also experience significant drinking water impacts under cyclone and flood (king tide) conditions, as shown in Figure 4.14. As in SI, RMI communities use a mix of water sources, even though communal RWH, wells and piped water are used much less by communities in RMI than those examined in SI. However, in addition to the importance of rainwater, RO has become a very important intervention to provide adequate drinking water in RMI, particularly during drought.

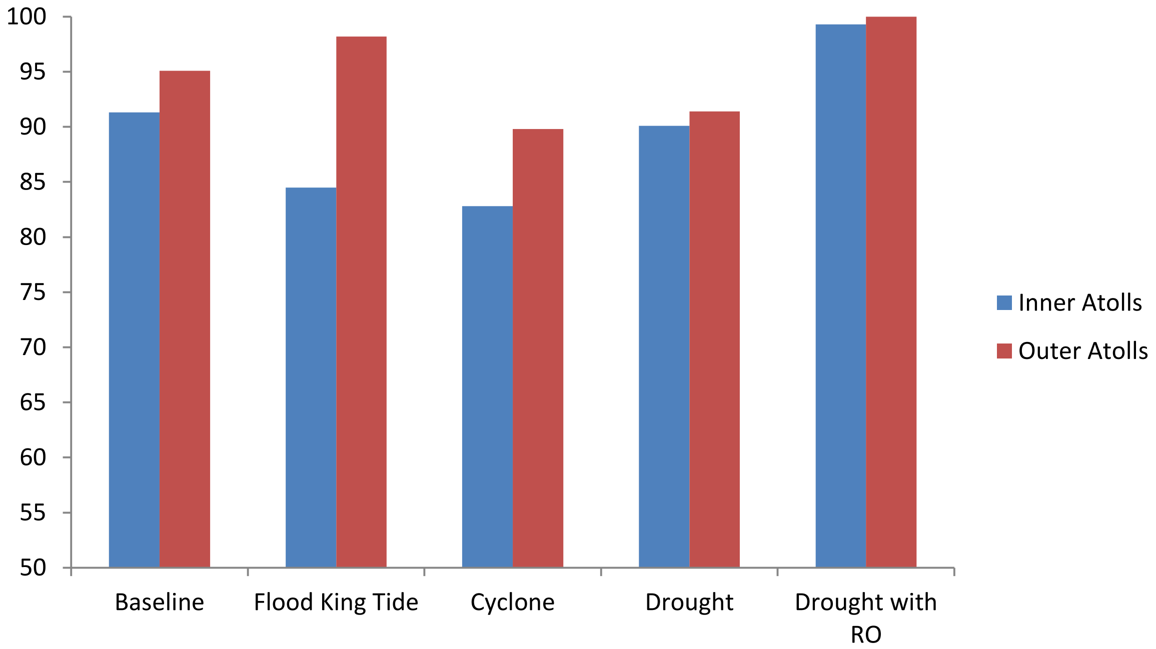

Figure 4.14. Atoll BBN: Comparison of impact of extreme events on proportion of community with adequate drinking water in "Inner" vs "Outer" atoll communities.

Findings 2: Impact of interventions

A sensitivity analysis for the atoll BBN (Table 4.4) indicates household (private) level RWH and RO are the two most influential water sources for drinking water within these communities. The overall impact of improving either RWH or RO on their own are similar, as shown in the two final sets of columns in Figure 4.15. External actors may take this as general support for focusing on lower cost/lower technology RWH interventions, however note that as model data is based on household behavior, a more nuanced interpretation would be that while there is no barrier to acceptance/use of RWH at the household scale, there remain practical limitations around storage/duration and rainfall that must still be considered. Likewise, for RO, practical limitations around power supply and water intake and brine disposal must be considered on a case-by-case basis. A final systemic consideration is that unlike the floodplain case, for atolls groundwater sources are often not available as additional backup.

Table 4.4. Atoll BBN sensitivity analysis: sensitivity of endpoint variable (proportion of community with adequate drinking water) to findings at other variables. Ranking lists most influential down to least influential variables.

Variables	Measures of sensitivity		
	Mutual Information	Percent	Variance of beliefs
[Drinking water endpoint]	*0.3137*	*100*	*0.0533756*
Private RW Collection	0.12151	38.7	0.0118194
Reverse Osmosis	0.04929	15.7	0.0026673
Extreme Events	0.0263	8.38	0.0017141
Community	0.01712	5.46	0.0009286
Contamination (Private RW)	0.00385	1.23	0.0003073
Contamination (Public Wells)	0.00371	1.18	0.000262
Private Well	0.00314	1	0.0002652
Region	0.00284	0.905	0.000233
Contamination (Public RWTs)	0.00137	0.437	0.0001147
Public RWT	0.00125	0.399	0.000094
Contamination (Private Wells)	0.00092	0.292	0.0000672
Contamination (City Water)	0.00078	0.247	0.0000574
Sanitation	0.00076	0.242	0.0000538
Public Well	0.00073	0.232	0.0000545
City Water (piped to house)	0.00047	0.15	0.0000343
Human Faecal Contamination (Private Wells)	0.00039	0.124	0.0000283
Human Faecal Contamination (Public Taps)	0.00013	0.0428	0.0000111
Season	0.00012	0.0369	0.0000085
Bottled/Packaged Water	0.0001	0.0314	0.0000073
Human Faecal Contamination (City Water)	0.00003	0.00893	0.0000021
Contamination (Public Taps)	0.00002	0.00776	0.0000018
Public Tap	0.00001	0.00166	0.0000004
Human Faecal Contamination (Public Wells)	0	0.000489	0.0000001

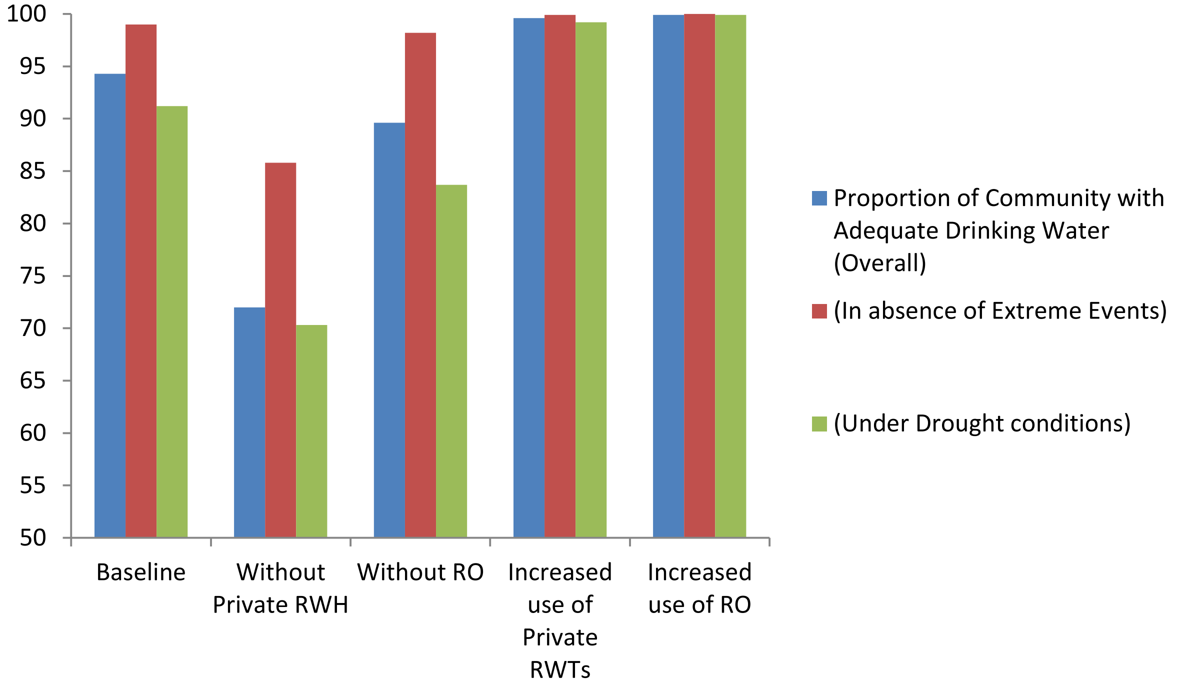

Figure 4.15. Atoll BBN: Impact of improving Private RWT vs RO on community drinking water.

Recommendation: Either RWH and RO have the potential to meet atoll community water needs. However, particularly where other water sources (e.g. groundwater) are unavailable, external actors should support use of both options to increase water security and resilience. Support may include increasing availability, storage volume and sustainable use of rainwater tanks at household level, including provision of hardware, and/or incentives for maintenance and damage repair, and technical training or other support for RO units.

Section 5: Integrating WaSH, CCA and DRR to achieve sustainable development in a changing world.

Background

Two major international agreements, both of which are critical to the future of PICs, were signed in 2015. In September 2015, countries adopted the SDGs and their 17 goals which seek "to end poverty, protect the planet and ensure prosperity for all" (UN 2016). In December 2015, 195 countries adopted "the first-ever universal, legally binding global climate deal" (UNFCCC 2016). Together these agreements represent significant and unprecedented global commitments and will shape the future of the planet. Both also represent major challenges – the SDGs are a significant step up from the MDGs (UN 2016) and many developing countries failed to meet the MDG targets. For the Paris Climate Agreement, we are entering new territory completely, with an agreement now in place to address the cause of climate change, mitigate our impacts on the global climate system and develop and implement climate change response strategies to assist in the adaptation realm.

What do these two global agreements mean for the WaSH sector in climate-vulnerable communities in the Pacific region? First, we know that water and sanitation for all is still a long way from being realized in many parts of the Pacific (WHO 2014). We also know that water underpins all development goals, so careful consideration of water systems, their uses and their vulnerabilities, is going to be increasingly important into the future. In addition, the water-focused SDG – Goal 6 – now goes beyond water and sanitation for all and extends it's reach substantially, which has major implications for sustainable development and adaptation to climate change.

If we look at the targets within Goal 6 (UN 2016), there are six with outcome focused objectives (6.1-6.6) and two with process and implementation objectives (6.a and 6.b), as follows:

- 6.1 By 2030, achieve universal and equitable access to safe and affordable drinking water for all
- 6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations
- 6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally
- 6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity
- 6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate
- 6.6 By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes
- 6.a By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies
- 6.b Support and strengthen the participation of local communities in improving water and sanitation management

A large focus of the Paris Climate Agreement is a recognition that industrialization and the burning of fossil fuels has contributed to the rate and nature of climate change (UNFCCC 2016). As a result, the PAC seeks to endorse significant mitigation efforts which will enable the global community to find new and more sustainable ways of producing energy and prosperity. In this context, mitigation does cut across some of the Goal 6 SDG targets (Table 5.1). More significantly, the adaptation and loss and damage components of the PAC have clear direct and indirect consequences for attaining all of the targets with Goal 6 of the SDGs (Table 5.1). Given this, it is clear that progression towards the sustainable development targets requires a thorough and integrated assessment of climate change impacts, adaptation opportunities and the feedback loops which link these objectives.

Table 5.1. How do the Paris Climate Agreement and the water-focused SDG targets (Goal 6) mesh together?

	Paris Climate Agreement – key aspects		
SDG – Goal 6	Mitigation	Adaptation	Loss and Damage
6.1 Water		Changes in rainfall, etc.	Extreme events – droughts and floods
6.2 Sanitation		Floods and droughts impact on sanitation infrastructure and safety	Lost infrastructure a major challenge
6.3 Reduce pollution	Reduced impacts of carbon-based pollution	Pollution influenced by increased infrastructure without wastewater treatment	Pollution influenced by increased flooding and periodicity of extremes
6.4 Water efficiency	Changed energy systems to use less water	Water efficiency threatened by population growth and demand	Water efficiency threatened by extreme events
6.5 IWRM	Energy systems integrated with water system	Adaptation must be integrated	Adaptation must be integrated
6.6 Protect ecosystems	Less water use for energy production	Thinking about water systems and how humans and ecosystems are connected	Ecosystems may protect and reduce loss and damage
6.a Build capacity		Need to look at ways to build capacity to develop and to adapt	Capacity to recover and adapt whilst still developing is critical
6.b Grow participation		Adaptation requires local participation	Participation in recovery efforts and plans to assess and respond to loss and damage

Can we attain the SDGs in the face of climate change?

Climate change means that we will always be moving (chasing our tails) to meet the SDGs – some communities, and indeed, entire PICs, may lurch from almost complete coverage for water and sanitation to almost none at all following extreme events like cyclones and floods (see Finau (1987) case study from Tonga, Martin and Watkins (2010) case study from Samoa and Figure 1.4 in Section 1). This reality, particularly in the dynamic Pacific region, will always make attaining the SDGs a significant challenge. Importantly, the impacts of extreme events will also mean that attaining the SDG targets will require ongoing and growing investment – it will not be a case of building services and infrastructure and achieving the targets – instead, it will be a case of maintaining the achieved targets in the long term. This has significant and long-reaching consequences both for the level and duration of investment required in the Pacific region.

Can progress towards the water-focused SGDs get in the way of our climate change responsibilities?

Current approaches to sustainable development, particularly those which focus on WaSHdo not tend to explicitly consider climate change and the future impacts anticipated on water systems. Indeed, WaSH development work focuses on end of pipe delivery of clean water and the provision of safe and accessible sanitation and hygiene, independently of the catchment, the water system and the environment. Goal 6 of the SDGs suggests that this approach cannot continue – practitioners and implementers of WaSH services and infrastructure should now report not just on ‘taps and toilets’ but also on how capacity and participation has been increased to also support water quality improvements, water efficiency activities, integration of WaSH into the broader Water Resource Management (IWRM) and aquatic ecosystem protection targets (UN 2015). This goes well beyond traditional WaSH and will require greater transdisciplinary cooperation to ensure that an IWRM approach is adopted in order to achieve all of the water-based objectives.

The biggest challenge associated with dovetailing the SDG and Paris Climate Agreement objectives comes with the timescale and realisation that a) we can't keep doing what we have been doing, and b) things will change through time and we need to consider those changes now. Bringing these concepts together is difficult, but in the context of sustainable development it is critical that an integrated approach is adopted. This obviously means that existing practices will need to be changed to ensure that WaSH practices (and water resource management more broadly) do not compromise future generations. Although sustainability has been an often stated goal for a very long time now, climate change and its impacts forces us to do more and to be much more forward-thinking in how we evaluate and address the challenge of sustainability. Indeed, climate change demands that we don't just evaluate our current progress and processes, but that we take into account the best available information on future trends (in climate, in resources, in development).

Conclusions

Climate change and sustainable development represent significant challenges through the Pacific region. A singular focus on one of these challenges will almost certainly create problems. Indeed, attaining the SDGs will be impossible without considering climate change impacts and incorporating measures to adapt and reduce vulnerability and loss and damage of social, cultural, economic and environmental attributes. Similarly, a singular focus on the Paris Climate Agreement and its objectives will not deliver sustainable development, especially in climate-vulnerable developing countries in the Pacific region. With this in mind, a coordinated and integrated approach is required to bring together the sustainable development and climate change adaptation challenges. For WaSH, a systems approach, integrating these aspects through the development and application of BBN models, offers the greatest opportunity for simultaneous consideration of all of the objectives that will build resilient and developed PICs.

Section 6: Opportunities for climate-resilient WaSH in the Pacific

There are many challenges and barriers to WaSH development in remote, rural communities in the Pacific region as demonstrated in the earlier sections of this report and many other published documents. However, on the basis of our research, we feel that there are also many opportunities for developing climate resilient WaSH in a way that does not erode traditional practices and lifestyles. Pulling together all of the knowledge presented in the preceding sections of this document, it is clear that there are five key principles to follow in order to design, develop, implement and practice sustainable and climate resilient WaSH in the Pacific, as follows:

1. **Adopt a systems approach**: Adopt an integrated systems approach to incorporate all dimensions of climate change and all of the connected aspects critical to developing sustainable water, sanitation and hygiene systems. A systems approach can enable decision makers to assess a) climate change impacts, b) current WaSH systems and their vulnerabilities, c) climatic and non-climatic aspects concurrently, d) intervention performance and unintended consequences (maladaptation) and e) the relative benefits of combined interventions, including software (e.g. maintenance) and hardware (e.g. rainwater tanks) approaches. This integrated and deliberately systematic approach to climate resilient WaSH also inherently includes the need to involve stakeholders from across sectors and have them provide the best available data to inform decision making.

2. **Use models and new tools to collect and analyse data**: To enable the implementation of risk management for the protection of water resources and provision of sustainable WaSH services, a framework and clear guidance on methods and tools for data collection, risk assessments, analyses and management is required. The use of models and digital technologies to support data collection, analysis and decision making opens up great opportunities in regions like the Pacific. New tools, including the BBNs and the CAPI tablet-based survey developed and implemented in the PACCWASH project are excellent examples of computer-based tools that can simplify complex tasks and provide managers and policy makers with increased capacity to make decisions in a systematic way. As outlined in point #1 above, a BBN model offers the capacity both to integrate diverse sources of data as well as to capture the connectivity within systems to ensure that decisions around particular climate change scenarios or intervention options can be made with reference to both the anticipated and unintended consequences on the system in question.

3. **Learn from regional activities**: There is a lot of work underway in the Pacific region, both on WaSH development and, increasingly, on climate change threats and adaptation options, so there is a growing opportunity to learn from the successes and failures of projects and policies implemented throughout the region. Coupled with a systems-understanding through the use of a BBN model (points #1 and #2 above), regional sharing will enable policy makers to make strong decisions whilst keeping in mind the local social, cultural, economic and environmental context of rural and remote PIC communities.

4. **Develop integrated governance structures**: To foster greater cooperation and coordination at the project and policy scales, opportunities exist for improved governance structures which will mainstream and drive climate change adaptation and disaster risk reduction activities across WaSH and other sectors. Specifically, Rural WaSH policies and plans should clearly define functions and responsibilities for reducing and managing climate and disaster risks at the national government, provincial government and community levels. This should include coordination between WaSH stakeholders and disaster management groups, in order to strengthen links between disaster and development WaSH, and align with existing institutional structures for disaster risk reduction and management.

5. **Build capacity and understanding**: Efforts to build capacity and understanding of the complexity of WaSH and climate change impacts are required throughout the Pacific region, as this will enhance adaptive capacity to climate variability and change. Targeted training to build capacity for risk management is necessary at all levels of government, down to the community. Joint capacity building exercises with climate change adaptation (CCA) and disaster risk management (DRM) actors could also improve cross-sectoral partnership and coordination.

Section 7: References

Adger, W. N. (2000) Social and ecological resilience: are they related? *Progress in Human Geography* 24(3), 347-364.

Al Radif, A. (1999) Integrated water resources management (IWRM): an approach to face the challenges of the next century and to avert future crises. *Desalination* 124, 145-153.

Amadore, L., Bolhofer, W. C., Cruz, R. V., Feir, R. B., Freysinger, C. A., Guill, S., Jalal, K. F., Iglesias, A., Jose, A., Leatherman, S., Lenhart, S., Mukherjee, S., Smith, J. B., & Wisniewski, J. (1996) Climate change vulnerability and adaptation in Asia and the Pacific: Workshop summary. *Water, Air, and Soil Pollution* 92(1-2), 1-12.

Arnell, N. W., van Vuuren, D. P., & Isaac, M. (2011) The implications of climate policy for the impacts of climate change on global water resources. *Global Environmental Change* 21(2), 592-603.

Bain, R., Luyendijk, R., & Bartram, J. (2013) Universal Access to drinking wáter: the role of aid. WIDER Working Paper No. 2013/88. United Nations University, World Institute for Development Economics Research, Helsinki, Finland, 44 pp.

Barnett, J. (2001) Adapting to climate change in Pacific Island Countries: The problem of uncertainty. *World Development* 29(6), 977-993.

Bartram, J.; Brocklehurst, C.; Fisher, M.; Luyendijk, R.; Hossain, R. (2014) Global monitoring of water supply and sanitation: A critical review of history, methods, and future challenges. *International Journal of Environmental Reseaech and Public Health* 11, 8137-8165.

Berlioz-Arthaud A., Kiedrzynski T., Singh N., Yvon J. F., Roualen G., Coudert C. and Uluiviti V. (2007). Multicentre survey of incidence and public health impact of leptospirosis in the Western Pacific. *Transactions of the Royal Society of Tropical Medicine and Hygiene* 101(7), 714-21.

Biswas, A. K. (2008) Integrated Water Resources Management: Is it working? *Water Resources Development* 24(1), 5-22.

Briguglio, L. (1995) Small island developing states and their economic vulnerabilities. *World Development* 23(9), 1615-1632.

Bukenya G. B. and Nwokolo N. (1990). Transient risk factors for acute childhood diarrhoea in an urban community of Papua New Guinea. *Trans R Soc Trop Med Hyg* 84(6), 857-60.

Carlton, E. J., Eisenberg, J. N., Goldstick, J., Cevallos, W., Trostle, J., & Levy, K. (2014) Heavy rainfall events and diarrhea incidence: The role of social and environmental factors. *American Journal of Epidemiology* 179(3), 344-352.

Carpenter, C. & Jones, P. (2004) An overview of integrated water resources management in Pacific Island Countries: A National and regional assessment. Status Report for GWP – Integrated Water Resources Management (IWRM), prepared for the South Pacific Applied GeoScience Commission (SOPAC), January 2004. SOPAC Miscellaneous Report 554, 66 pp.

Caviglia-Harris, J.; Hall, S.; Mulllan, K.; Macintyre, C.; Bauch, S. C.; Harris, D.; Sills, E.; Roberts, D.; Toomey, M.; Cha, H. (2011) Improving Household Surveys Through Computer-Assisted Data Collection: Use of Touch-Screen Laptops in Challenging Environments. *Field Methods* 24, (1), 74-94.

Christensen, J. H., Krishna Kumar, K, Aldrian, E., An, S. -I., Cavalcanti, I. F. A., de Castro, M., Dong, W., Goswami, P., Hall, A., Kanyanga, J. K., Kitoh, A., Kossin, J., Lau, N. -C., Renwick, J., Stephenson, D. B., Xie, S. -P. & Zhou, T. (2013) Climate Phenomena and their Relevance for Future Regional Climate Change. *In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P.M. Midgley, eds.). Cambridge University Press, Cambridge, United Kingdom (pp. 1217-1308).

Chui, T. F. M., & Terry, J. P. (2013) Influence of sea-level rise on freshwater lenses of different atoll island sizes and lens resilience to storm-induced salinization. *Journal of Hydrology* 502, 18-26.

Civil Society WaSH Fund (2015) *Civil Society Organisations and WaSH Service Delivery in the Pacific: Synthesis Report of the Pacific Regional Learning Event*.

Clarke M., Feeny S. and Donnelly J. (2014). Water, Sanitation and Hygiene Interventions in the Pacific: Defining, Assessing and Improving 'Sustainability'. *European Journal of Development Research* 26(5), 692-706.

Cocklin, C., & Keen, M. (2000) Urbanization in the Pacific: environmental change, vulnerability and human security. *Environmental Conservation*, 27(04), 392-403.

Cumming, O., Elliott, M., Overbo, A., & Bartram, J. (2014) Does global progress on sanitation really lag behind water? An analysis of global progress on community- and household-level access to safe water and sanitation. *PLoS ONE* . In press.

Dengler L. and Preuss J. (2003). Mitigation lessons from the July 17, 1998 Papua New Guinea tsunami. *Pure and Applied Geophysics* 160(10-11), 2001-31.

Dosskey, M. G., Vidon, P., Gurwick, N. P., Allan, C. J., Duval, T. P. and Lowrance, R. (2010) The role of riparian vegetation in protecting and improving chemical water quality in streams. *Journal of the American Water Resources Association* 46(2), 261-277.

Ellison, J. C. (2009) Wetlands of the Pacific Island region. *Wetlands Ecology and Management* 17(3), 169-206.

Evans, et al. (2013) *Public health and social benefits of at-house water supplies*. Univ of Leeds.

Falkenmark, M., Jagerskog, A. & Schneider, K. (2014) Overcoming the land-water disconnect in water-scare regions: time for IWRM to go contemporary. *International Journal of Water Resources Development* 30(3), 391-408.

Fewtrell, L., Kaufmann, R. B., Kay, D., Enanoria, W., Haller, L., & Colford Jr, J. M. (2005) Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis. *The Lancet infectious diseases* 5(1), 42-52.

GEF (Global Environmental Facility) (2004) From Ridge to Reef: Water, environment, and community security. GEF Action on Transboundary Water Resources. https://www.thegef.org/gef/sites/thegef.org/files/publication/GEF_RidgetoReef_CRA_lores.pdf Accessed November 19 2014.

Ghassemi F., Jakeman A. J. and Jacobson G. (1990). Mathematical modelling of sea water intrusion, Nauru Island. *Hydrological Processes* 4(3), 269-81.

Greenwell J., McCool J., Kool J. and Salusalu M. (2013). Typhoid fever: hurdles to adequate hand washing for disease prevention among the population of a peri-urban informal settlement in Fiji. *Western Pac Surveill Response J* 4(1), 41-5.

Griggs J. E. and Peterson F. L. (1993). Ground-water flow dynamics and development strategies at the atoll scale. *Ground Water* 31(2), 209-20.

Guerrier G., Foster H., Metge O., Chouvin C. and Tui M. (2013). Cultural contexts of swine-related infections in Polynesia. *Clin Microbiol Infect* 19(7), 595-9.

GWP (Global Water Partnership) (2007) *Climate Change Adaptation and Integrated Water Resource Management – An Initial Overview*, Policy Brief 5.

GWP (Global Water Partnership) (2010) What is IWRM? http://www.gwp.org/The-Challenge/What-is-IWRM/ accessed 11 May 2014

Hadwen, W.L., Capon, S.L., Ploczanska, E., Rochester, W., Marin, T., Bay, L., Pratchett, M., Green, J., Cook, B., Berry, A., Lalonde, A., & S. Fahey, S. (2012) Climate change responses and adaptation pathways in Australian coastal ecosystems: Synthesis Report. Report to the National Climate Change Adaptation Research Facility, Gold Coast, Australia. Pp. 359.

Hadwen, W. L., Powell, P., MacDonald, M. C., Elliott, M., Chan, T., Gernjak, W. and Aalbersberg, W. G. L. (2015), Putting WaSH in the water cycle: Climate change, water resources and the future of water, sanitation and hygiene challenges in Pacific Island Countries. Journal of Water, Sanitation and Hygiene for Development 5(2), 183-191.

Hanna, E. (2013) 1.14 - Vulnerable States: Pacific Island Countries. *In: Climate Vulnerability* (R. A. Pielke, ed.), Oxford: Academic Press, United Kingdom, pp. 165-182.

He, X. (2013) Mainstreaming adaptation in integrated water resources management in China: from challenge to change. *Water Policy* 15, 895-921

IPCC (2013a) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P. M. Midgley (Eds.), Cambridge University Press, Cambridge, United Kingdom pp. 1535.

IPCC (2013b) Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P. M. Midgley eds.), Cambridge University Press, Cambridge, United Kingdom pp. 33.

Irving, D.B. S.E. Perkins, J.R. Brown, A. Sen Gupta, A.F. Moise, B.F. Murphy, L.C. Muir, R.A. Colman, S.B. Power, F.P. Delage, & J.N. Brown (2011) Evaluating global climate models for the Pacific island region. *Climate Research* 49,169-187.

IUCN (2013) Ridge to Reef - Managing waters from source to sea. http://www.iucn.org/about/work/programmes/water/wp_our_work/wp_our_work_ridgetoreef/ Accessed November 19 2014.

Jagals, P., Grabow, W. O. K. and E. Williams (1997) The effects of supplied water quality on human health in an urban development with limited basic subsistence facilities. *Water SA* 23(4), 373-378.

Keen M. (2003). Integrated water management in the South Pacific: Policy, institutional and socio-cultural dimensions. *Water Policy* 5(2), 147-64.

Kirtman, B., Power, S. B., Adedoyin, J. A., Boer, G. J., Bojariu, R., Camilloni, I., Doblas-Reyes, F. J., Fiore, A. M., Kimoto, M., Meehl, G. A., Prather, M., Sarr, A., Schär, C., Sutton, R., van Oldenborgh, G. J., Vecchi, G. & Wang, H. J. (2013) Near-term Climate Change: Projections and Predictability. In T. F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S. K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex & P. M. Midgley (Eds.), Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 953-1028). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Koda K., Manpuku Y., Kobayashi T., Ishida S., Yoshimoto S. and Okubo M. (2013). A study of the sealing effect in the observation well of the freshwater lens at Laura Island, Republic of the Marshall Islands. *Japan Agricultural Research Quarterly* 47(3), 257-72.

Leatherman, S. P. (1996) Shoreline stabilization approaches in response to sea level rise: U.S. experience and implications for Pacific Island and Asian nations. *Water, Air, and Soil Pollution* 92(1-2), 149-157.

Ludwig, F., van Slobbe, E. & Cofine, W. (2013) Climate change adaptation and integrated water resource management in the water sector. *Journal of Hydrology (online only),* http://dx.doi.org/10.1016/j/hydrol.2013.08.010

McLeod, E., Hinkel, J., Vafeidis, A. T., Nicholls, R. J., Harvey, N., & Salm, R. (2010) Sea-level rise vulnerability in the countries of the Coral Triangle. *Sustainability Science* 5(2), 207-222.

Meehl, G. A. (1996) Vulnerability of freshwater resources to climate change in the Tropical Pacific region. Paper presented at the *Climate Change Vulnerability and Adaptation in Asia and the Pacific: Proceedings of a workshop held in Manila, Phillipines, 15-19 January 1996.*

Meehl, G. A. (1997) Pacific region climate change. *Ocean & Coastal Management* 37(1), 137-147.

Miller, F., Bowen, K., Va, D., Bac Tan Sinh, Nguyen Quynh Anh, Puamau, E. S., Catmur, C., Dang Lan Huong, Vu Canh Toan, & McMichael, A. J. (2013) Climate Change Adaptation in the Health and Water Sectors – A Three Country Study: an evaluation of factors that influence the development of adaptation measures in Cambodia, Vietnam and Fiji Synthesis Report (pp. 35). Canberra, Australia: The Australian National University.

Mimura, N., Nurse, L., McLean, R. F., Agard, J., Briguglio, L., Lefale, P., Payet, R. & Sem, G. (2007) Small islands. Climate Change 2007: Impacts, Adaptation and Vulnerability. In M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. v. d. Linden & C. E. Hanson (Eds.), Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 687-716). Cambridge, United Kingdom: Intergovernmental Panel on Climate Change.

Morgan, L. K., & Werner, A. D. (2014) Seawater intrusion vulnerability indicators for freshwater lenses in strip islands. *Journal of Hydrology* 508, 322-327.

Ozdemir, et al. (2011) Rainwater harvesting practices and attitudes in the Mekong Delta of Vietnam. *JWASH Dev*. 1:171.

Perkins, S. E., Irving, D. B., Brown, J. R., Power, S. B., Moise, A. F., Colman, R. A., & Smith, I. (2012) CMIP3 ensemble climate projections over the western tropical Pacific based on model skill. *Climate Research* 51(1), 35-58.

Phan, T.D., Smart, J. C. R., Capon, S. J., Hadwen, W. L. and Sahin, O. (2016) Applications of Bayesian Belief Networks in water resource management: A systematic review. Environmental Modelling and Software 85: 89-111.

Pittock, A. B., Walsh, K., & McInnes, K. (1996) Tropical cyclones and coastal inundation under enhanced greenhouse conditions. *Water, Air, and Soil Pollution* 92(1-2), 159-169.

Poustie, M. S., & Deletic, A. (2014) Modeling integrated urban water systems in developing countries: case study of Port Vila, Vanuatu. *Ambio* 43(8), 1093-1111.

Prüss-Ustün, A., Bartram, J., Clasen, T., Colford, J. M., Cumming, O., Curtis, V., Bonjour, S., Dangour, A. D., De France, J., Fewtrell, L., Freeman, M. C., Gordon, B., Hunter, P. R., Johnston, R. B., Mathers, C., Mäusezahl, D., Medlicott, K., Neira, M., Stocks, M., Wolf, J. & Cairncross, S. (2014) Burden of disease from inadequate water, sanitation and hygiene in low-and middle-income settings: a retrospective analysis of data from 145 countries. *Tropical Medicine & International Health*. 19(8), 894-905 doi:10.1111/tmi.12329

Rapaport M. (1990). Population pressure on coral atolls: trends and approaching limits. *Atoll Res Bull*(340), 1-33.

Roy P. and Connell J. (1991). Climatic change and the future of atoll states. *Journal of Coastal Research* 7(4), 1057-75.

Samaniego, L., & Bardossy, A. (2006) Simulation of the impacts of land use/cover and climatic changes on the runoff characteristics at the mesoscale. *Ecological Modelling* 196(1-2), 45-61.

Shaheed, et al. (2014) Why "improved" water sources are not always safe. *Bull WHO*. 92:283.

Singh, R. B., Hales, S., de Wet, N., Raj, R., Hearnden, M., & Weinstein, P. (2001) The influence of climate variation and change on diarrheal disease in the Pacific Islands. *Environmental Health Perspectives* 109(2), 155-159.

Smits, S., Batchelor, C., Schouton, T., Moriarty, P., Butterworth, J. (2009) Effective WaSH sector adaptation to climate change through improved governance. *Waterlines*. 28, 210-218.

SOPAC and ADB (2003) Pacific Regional Action Plan on Sustainable Water Management. Fiji Islands. Accessed on January 22 2015 at: http://www.pacificwater.org/userfiles/file/Pacific%20RAP%20on%20SWM.pdf

SOPAC (Secretariat of the South Pacific, Applied Geoscience and Technology Division) (2014) Global Environment Facility Pacific IWRM Project: Implementing Sustainable Water Resources and Wastewater Management in Pacific Island Countries. http://www.pacific-iwrm.org/index.html Accessed 14 July 2014.

South G. R., Skelton P. A., Veitayaki J., Resture A., Carpenter C., Pratt C. and Lawedrau A. (2004). The Global International Waters Assessment for the Pacific Islands: aspects of transboundary, water shortage, and coastal fisheries issues. *Ambio* 33(1-2), 98-106.

Terry, J. P., Kahsai, K., Grover, V. & Mayfield, C. (2007) Integrated water resources management (IWRM): Needs and training for the Oceania Region. *Advances in Geosciences*, Volume 11: Hydrological Science (HS), 313-324.

Thompson C. N., Kama M., Acharya S., Bera U., Clemens J., Crump J. A., Dawainavesi A., Dougan G., Edmunds W. J. and Fox K. (2014). Typhoid fever in Fiji: a reversible plague? *Tropical Medicine & International Health* 19(10), 1284-92.

UN (2014) List of Least Developed Countries in 2014. United Nations. New York. http://www.un.org/en/development/desa/policy/cdp/ldc/ldc_list.pdf Accessed 22 May 2014.

UNICEF (2013) *A snapshot of water supply in East Asia and the Pacific – 2013 regional analysis and update.* UNICEF East Asia and Pacific Regional Office, Bangkok, Thailand.

UNICEF (2014) *WaSH & Resilience*. http://rsr.akvo.org/media/db/project/3668/document/WaSH resilience PICs 29 Oct 2014.pdf.

van der Velde M., Green S. R., Vanclooster M. and Clothier B. E. (2007). Sustainable development in small island developing states: Agricultural intensification, economic development, and freshwater resources management on the coral atoll of Tongatapu. *Ecological Economics* 61(2-3), 456-68.

White, I., Falkland, T., Metutera, T., Metai, E., Overmars, M., Perez, P. And Dray, A. (2007) Climatic and human influences on groundwater in low atolls. *Vadose Zone Journal* 6, 581-590.

White, I. and Falkland, T. (2010) Management of freshwater lenses on small Pacific islands. *Hydrogeology Journal* 18, 227-246.

Whittington, D. (2000) *Designing household survey questionnaires for developing countries - Lessons learned from 15 years of the Living Standards Measurement Study*; The World Bank: WaSHington, DC, pp 1-356.

WHO (2008) *World Health Statistics 2008*. World Health Organization, Geneva.

WHO & UNICEF (2013) *UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation, 2010.* Progress on Sanitation and Drinking-Water: 2010 Update. World Health Organisation, Geneva and UNICEF, New York.

WHO & UNICEF (2014) *Progress on sanitation and drinking-water – 2014 update*. World Health Organization, Geneva.

WHO & SOPAC (2009) *Sanitation, Hygiene and drinking-water in the Pacific Island countries – Converting commitment into action*. World Health Organization and the Pacific Island Applied Geoscience Commission. Geneva, Switzerland. Pp. 72.

WHO (2013) *World Health Statistics 2013*. World Health Organization, Geneva.

Wohlfahrt D. J. and Kukyuwa K. (1982). Village rural water supplies in the Western Highlands Province of Papua New Guinea. *P N G Med J* 25(3), 168-72.

Wolf, J., Prüss-Ustün, A.,Cumming, O., Bartram, J., Bonjour, S., Cairncross, S., Clasen, T., Colford, J. M., Curtis, V., De France, J., Dangour, A. D., De France, J., Fewtrell, L., Freeman, M. C., Gordon, B., Hunter, P. R., Jeandron, A., Johnston, R. B., Mäusezahl, D., Mathers, C., Neira, M., Wolf, J. … & Higgins, J. P. T. (2014) Assessing the impact of drinking water and sanitation on diarrhoeal disease in low- and middle-income settings: systematic review and meta-regression. *Tropical Medicine & International Health.* 19(8), 928-942. doi:10.1111/tmi.12331

World Bank (2000) Cities, Seas and Storms: Managing Change in Pacific Island Economies. *In: Adapting to Climate Change*. (Vol. IV, pp. 135). Washington DC, USA: World Bank.