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Fragile Paradise: Health Impacts of Climate Change in Pacific Island Countries

by

Dr Lachlan McIver

MBBS MPH&TM JCC(Anaes) FACRRM FACTM

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Declaration

The contents of this thesis are the result of original research and have not been submitted to any other university or institution.

The majority of the work described herein was undertaken while I was on assignment with the World Health Organization (WHO) South Pacific office, based in Suva, Fiji from 2011 to 2013. I accepted this assignment on the understanding that I would carry out a doctoral programme of research work coupled to the operational responsibilities required of me by WHO. My research work was thus supported by WHO and the ANU over the four years that followed the commencement of my assignment in 2011.

My role was initially as the WHO Climate Change and Health Technical Officer and subsequently the project's lead technical advisor. As such, I was the principal investigator for the regional research project investigating the health impacts of climate change in Pacific island countries and compiling evidence-based adaptation strategies to minimise these risks to health. This involved coordination of all of the research and operational aspects of the work at the regional level. At the country level I led all the research activities, including design, data collection, analysis and implementation, working alongside the national "focal point" in each instance for all aspects of the project research work, carried out in collaboration with the WHO consultants engaged for each group of countries.

I had the support of The Australian National University, WHO and the Ministry of Health (or equivalent) in each Pacific island country to lead this research project and incorporate the resultant publications into this thesis. This support is reflected in the letters of permission provided by the countries and the letters of support provided by all of the co-authors of the papers included in the thesis (see below).

In addition to the published papers contained within this thesis, I was also the lead author for each country's National Climate Change and Health Action Plan (or equivalent) - with the exception of Samoa, whose work is not included in this thesis - and for the final project technical report published by WHO in late 2015. The latter document, entitled *Human Health and Climate Change in Pacific Island Countries*, summarises the findings of the vulnerability assessment and adaptation planning process for each country and provides a

series of recommendations from WHO to assist countries in implementing effective adaptation measures. The WHO report addresses primarily the policy and implementation aspects of adaptation, while the research papers in this thesis provide the vital additional technical perspective on the process, findings and outcomes of the project.

Several of the papers included in this thesis built on the findings of the WHO-supported project, but resulted from subsequent research that I led following the completion of my assignment with WHO.

All of those who made substantive contributions to the project outputs and published papers have been gratefully and respectfully mentioned, either in the following Acknowledgements section and/or in the papers themselves. The order of authorship for each publication accords with the guidelines provided by the International Committee of Medical Journal Editors (ICMJE).

I had the unanimous support of my collaborators in co-authoring - and in most cases lead-authoring - the peer-reviewed publications included in this thesis, given my role as principal investigator for all of the relevant research activities in each of the project countries (except Samoa). I conducted the needs and capacity assessments, consulted with the relevant stakeholders, designed the methodology, collected the data, conducted or collaborated on the analyses, drafted the manuscripts and coordinated the dissemination of the key findings. I was involved with all of the technical and analytical aspects of the research. In the few instances where co-investigators with particular expertise in specific analytical techniques were required to take the lead on various aspects of the data analysis, this process was consistently collaborative and dependent upon my contributions.

A summary of my contribution to each paper is included in Table 1 below. This statement has been reviewed and endorsed by all of the co-authors of papers included in this thesis. Their signed confirmations are available upon request.

Table 1. Contribution of doctoral candidate (Dr Lachlan McIver) to the key components of each publication included as discrete chapter in thesis

Chapter number	Title of paper	Journal	Status	Authors (in order)	Candidate's contribution
4	Health impacts of climate change in Pacific island countries: a regional assessment of vulnerabilities and adaptation priorities	<i>Environmental Health Perspectives</i>	Published	McIver L, Kim R, Woodward A, Hales S, Spickett J, Katscherian D, Hashizume M, Honda Y, Kim H, Iddings S, Naicker J, Bambrick H, McMichael A & Ebi K	<ul style="list-style-type: none"> - Lead investigator for regional project - Collaborated on vulnerability assessment and adaptation planning work in all countries - Led drafting of final project output for most countries - Led authorship of paper
5	Assessment of Climate-sensitive Infectious Diseases in the Federated States of Micronesia	<i>Tropical Medicine and Health</i>	Published	McIver L, Hashizume M, Kim H, Honda Y, Pretrick M, Iddings S & Pavlin B	<ul style="list-style-type: none"> - Collected data and collaborated on analysis - Guided stakeholder consultations, vulnerability assessment and adaptation planning processes - Led authorship of project output and published paper
6	Health Impacts of Climate Change in Vanuatu: An Assessment and Adaptation Action Plan	<i>Global Journal of Health Sciences</i>	Published	Spickett J, Katscherian D & McIver L	<ul style="list-style-type: none"> - Collaborated on stakeholder consultation, vulnerability assessment and adaptation planning processes - Co-authored project output and published paper
7	Assessment of the Health Impacts of Climate Change in Kiribati	<i>International Journal of Environmental Research and Public Health</i>	Published	McIver L, Woodward A, Davies S, Tibwe T & Iddings S	<ul style="list-style-type: none"> - Collaborated on stakeholder consultation, vulnerability assessment and adaptation planning processes - Collected data and conducted preliminary analysis - Led authorship of project output and published paper
8	Climate Change and Health in Fiji: Environmental Epidemiology of Infectious Diseases and Potential for Climate-Based Early Warning Systems	<i>Fiji Journal of Public Health</i>	Published	McIver L, Naicker J, Hales S, Singh S & Dawainavesi A	<ul style="list-style-type: none"> - Collected data - Shared analytical workload (quantitative epidemiological and geographic information system analysis) - Led authorship of project technical outputs and published paper
9	Early Warning Systems for Climate-Sensitive Infectious Diseases in Fiji: Lessons Learned and Next Steps	<i>Fiji Journal of Public Health</i>	Published	McIver L, Hales S, Dear K & Kim R	<ul style="list-style-type: none"> - Shared development and design of paper - Collected data for analysis - Interpreted results - Led authorship of paper
10	Climate Change, Overcrowding and Non-Communicable	<i>Annals of the Australasian College of</i>	Published	McIver L, Viney K, Harley D, Hanna E & Kienene T	<ul style="list-style-type: none"> - Shared development and design of paper - Compiled data

	Diseases: the “Triple Whammy” of Tuberculosis Transmission Risk in Pacific Atoll Countries	<i>Tropical Medicine</i>			<ul style="list-style-type: none"> - Developed mechanistic model - Led authorship of paper
11	A “Healthy Islands” Framework for Climate Change in the Pacific	<i>Health Promotion International</i>	Published	Mclver L, Bowen K, Hanna E & Iddings S	<ul style="list-style-type: none"> - Led development and design of paper - Adapted health promotion model - Led authorship of paper



Signed:

Lachlan Mclver

July 2015

Acknowledgements

I write these words in Port Vila, Vanuatu, in early May 2015, surrounded by the evidence of the impact of Tropical Cyclone Pam. The devastation caused by this tropical storm – the most severe in the Pacific region in living memory – included the destruction of tens of thousands of homes and the displacement of over half of Vanuatu’s population.

After spending most of the last five years in the Pacific, I consider this beautiful part of the world – the Blue Continent, as it’s become known – to be my home. However, the beauty of the region, including its spectacular island geography and culture, is associated with significant fragility.

Vanuatu is one of the most disaster-prone countries in the world and, as a small island developing state, it is one of the most vulnerable in the world to the impacts of climate change. This thesis contains some of the most detailed and up-to-date information available regarding the climate change and health vulnerabilities of Pacific island countries, including Vanuatu, and suggests some suitable health systems adaptation and resilience-building strategies. What this thesis cannot adequately describe, however, is the human impact of the changes that have been wrought upon our planetary ecosystem.

At least eleven people are known to have died from direct trauma caused by Cyclone Pam. A greater number of fatalities was anticipated; it is testament to the timely interventions of government agencies and non-government organisations, and the wisdom, ingenuity and sheer resilience of *ni-Vanuatu* communities, that the death toll was not much higher. Health facilities all over the country were inundated for weeks with cases of respiratory and diarrhoeal diseases. Wound infections are now being seen in the clinics and emergency departments, as the injuries sustained from the disaster and recovery effort fester, and the country has just seen its first reported case of Zika virus (a mosquito-borne disease previously unknown in Vanuatu) amidst an epidemic of dengue fever.

All of these manifestations of ill-health – and many others hidden from view, such as the psychological trauma suffered by so many – may be linked to the cyclone. This cyclone, in turn, must be interpreted from a long-term, macroscopic perspective, which sees the return period for extreme weather events diminishing (such that hydrometeorological disasters like

this are becoming more frequent), as the forces driving anthropogenic climate change continue, unabated.

My concern about these and other health hazards posed by climate change and climate-related disasters was a key motivation for me to embark on this journey; what has inspired me since are the people I have encountered along the way.

There are many individuals who deserve to be acknowledged as having assisted and supported me in myriad, profound ways over the last few years. They include, of course, the brilliant group of academic supervisors who provided the guidance and good humour that was the bedrock on which I was able to build: Liz Hanna, the indefatigable and eternally optimistic Chair of my panel; Simon Hales, whom I have treasured as a mentor since my arrival in the Pacific; Dave Harley, who has been an ever-patient and pragmatic source of advice; and Keith Dear, without whose technical and analytical expertise my experience, and these results, would have suffered. What began as a professional relationship with these four collaborators is now a firm friendship, for which I am most appreciative.

I must give special thanks to two people in particular, who took a chance on me and gave me the opportunity to pursue my professional interests and passion for research. Steve Iddings, the former Team Leader for Environmental Health and Emergency Humanitarian Action at the WHO South Pacific office, created the assignment for which I applied, accepted me for the position and supported my research agenda. He trusted my judgement and allowed me the autonomy to roam around the region, carrying out this important work. Steve also taught me more than I could have ever cared to know about the actions and interactions of WHO and its partners in the Pacific, as well as about the technical and managerial aspects of environmental health practice and disaster management. This knowledge has since served me extremely well, not least when I found, to my astonishment, that I was required to act in Steve's capacity for several months following his departure. I will be eternally grateful to Steve for opening up this world to me and showing such faith in my abilities.

The other person to whom I owe a deep debt of gratitude, from the earliest steps of my journey, is Tony McMichael. Tony was gracious enough to listen to my ideas when I first approached him about my WHO assignment and the possibility of a PhD. He was then generous enough to join my supervisor panel and provided invaluable guidance (or, as Liz so

whimsically refers to it “sprinkled his fairy dust”) as the journey progressed. I believe I am one of the last students – perhaps the final – that Tony took under his wing, and I am privileged to have benefitted from his wisdom right up until the days before he passed away late last year. I am extremely proud to have Tony as a posthumous co-author on the most important of the papers in this thesis (Chapter 5), and the corresponding WHO report entitled “Human Health and Climate Change in Pacific Island Countries”, both of which are to be published this year. A textbook chapter which attempts to summarise Tony’s contribution to this field of work, and its relevance in the Pacific, has been included as an annex to this thesis.

I am also very grateful to the friends who supported me – in fact, “put up with me”, would be more accurate – throughout this journey, and with whom I’m very much looking forward to getting reacquainted. Special thanks must go to Simon Rice, Kathryn Bowen and Naomi Godden, who have been consistent sources of encouragement, advice and fellow thesis-sufferer sympathy since the beginning, and with whom I hope to collaborate on the as-yet inadequately addressed issues of climate change and its effects on mental health, women’s health, social justice and health systems in developing countries.

My mother, Mary-Jane, and my sister, Kirsty, have been unfailing sources of loving support over these often difficult years. I thank them both with all the love I possess. My father, Ian McIver, who passed away seventeen years ago would, I am certain, be immensely proud of this achievement.

Finally, I dedicate this work to the Pacific Islanders I now count among my family and friends. I hope this addition to our collective knowledge enables the informing of policy, empowerment of communities and avoidance of the most serious threats that climate change poses to the health and well-being of our Pacific people.

Abstract

Pacific island countries are among the most vulnerable in the world to the impacts of climate change, including the many and varied effects on human health. The vast majority of these health impacts are expected to be negative and the burden of climate change-attributable ill-health will be maldistributed, with the greatest suffering likely to be experienced by the poor.

The objectives of the research described in this thesis were:

- a) To critically appraise various methods of assessing climate change and health vulnerabilities in Pacific island countries;
- b) To establish the key climate-sensitive health risks in each country; and
- c) To develop an evidence base for health systems adaptation to climate change in the Pacific region.

Thirteen countries participated in this regional climate change and health vulnerability assessment and adaptation planning project between 2011 and 2013: Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu. This project, supported by the World Health Organization South Pacific office, employed a range of quantitative and qualitative techniques in the assessment and stratification of climate change and health risks for each country and the development of regional and country-specific adaptation strategies.

The thesis presents the results of these analyses and describes in detail the predominant risks to health posed by climate change in the Pacific. These include: injuries and trauma; compromised safety and security of water and food (leading to malnutrition and gastrointestinal infections); vector-borne diseases; heat-related illnesses; zoonoses; respiratory ailments; psychological and emotional ill-health; increasing morbidity and mortality from non-communicable diseases; population pressures; and increased strain and pressure on health systems in these small island developing states.

Correspondingly, the adaptation themes common across the region relate to improving the safety and security of food supplies and water, sanitation and hygiene facilities; enhancing

infectious disease surveillance and response capabilities; building resilience within health systems and of health infrastructure; and increasing the accuracy and efficiency of communication and collaboration between the health sector and other agencies.

The results of these assessments have been compiled into national climate change and health adaptation plans for each country, and synthesised in a World Health Organization report published in late 2015.

The thesis summarises the main categories of adaptation strategies planned around the region and the health systems and policy landscape within which adaptation is taking place. In doing so, the thesis combines overviews of the vulnerabilities and adaptation plans from a regional perspective, along with examples of specific countries, including Federated States of Micronesia, Fiji, Kiribati and Vanuatu.

The overall aim of this work is to enhance the ability of individuals, communities and health systems in the region to withstand the pressures and hazards posed by climate change, by providing a body of scientific evidence and a basis for sound policies aimed at protecting the health of Pacific Island people. It is clear that this will necessarily involve substantial support from wealthier countries – the messages are increasingly clear; the audience is global; and the timing is urgent.

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Chapter One

Introduction

1.1 Introduction to the Pacific

The Pacific region is home to several million people, inhabiting tens of thousands of islands shared between more than twenty countries and territories that together constitute the so-called Blue Continent (Map 1.1).



Map 1.1. Pacific island countries and territories (showing Exclusive Economic Zones, or EEZs).

Source: CartoGIS, College of Asia and the Pacific, The Australian National University

In few other places in the world are the effects of climate change as visible or tangible as the Pacific. The leaders of the region know this, and are among the most outspoken on the global stage on issues such as climate change mitigation and disaster risk reduction - related risks in one of the most disaster-prone and climate change-susceptible regions of the world.^{1,2}

In the Pacific, climate change is not an environmental issue. Nor is it only an issue affecting health. Rather, it represents both an existential threat and an overarching impediment to development and the betterment of the lives of Pacific Island people.³

As Vanuatu's President Baldwin Lonsdale stated, incisively and emotionally, regarding the impact and implications of Cyclone Pam in March 2015: "It's a setback for the government and the people of Vanuatu... all this development has been wiped out. Climate change is contributing to the disasters in Vanuatu... the hazards of global warming affect our people in different ways, and it is a catastrophe that impinges on our rights ...and our survival into the future"¹. The imperative to address this "catastrophe" by researching the impacts of climate change on human population health in the Pacific is the key premise of this thesis.

1.2 Background to climate change and health in the Pacific

Assessment of the climate change vulnerabilities of Pacific island countries (PICs) commenced in the early 1990s, with the compilation and submission of Initial National Communications to the United Nations Framework Convention on Climate Change (UNFCCC) and, for the least-developed countries (LDCs) in the region, preparation of National Adaptation Programmes of Action (NAPAs). At this time, the international public health community, led by the World Health Organization (WHO) was still in the preliminary stages of conducting research and providing guidance to countries – largely based on informed speculation – on assessing health vulnerabilities and proposing adaptation strategies to manage these threats to health.⁴ Thus, the health sector's contributions to these early assessments and adaptation plans were relatively light, and lacking in strong evidence to support the details contained therein.⁵

The late 2000s saw a significant scale-up of political commitment and financial and technical support for PICs to address climate change vulnerabilities, including impacts on human health. The key policy instruments for this at a regional level were WHO's *Regional Framework for Action to Protect Human Health from Effects of Climate Change in the Asia-Pacific Region*⁶ and the Pacific Health Ministers' *Madang Commitment*,⁷ which committed all countries in the region to action on climate change and health, with particular emphasis on vulnerability assessment and adaptation planning.

These were the much-needed catalysts for the initiation of this focused, evidence-based, policy-oriented climate change and health research in Pacific region.

¹ <http://www.weather.com/storms/hurricane/news/cyclone-pam-vanuatu-climate-change>

With guidance from WHO and funding from governments (notably Japan and the Republic of Korea) and international donor agencies (principally, the Global Environment Facility – GEF), a regional climate change and health project commenced in the Pacific in 2010. This project, which forms the foundation of this thesis, was conducted via different processes in each country; the end result for almost all countries involved was the compilation of a National Climate Change and Health Action Plan (NCCHAP), or an equivalent thereof. The processes and outcomes of this work are described in this thesis, in addition to the corresponding WHO report (see below).

1.3 Aims and scope

The research presented in this thesis formed the foundation of the climate change and health vulnerability assessments and adaptation planning processes in thirteen Pacific island countries (PICs): Cook Islands, Federated States of Micronesia (FSM), Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu.

The overall objectives of this research and related project work were:

- to assess the vulnerabilities of Pacific island countries to the likely health impacts of climate change;
- to prioritise each country's climate-sensitive health risks according to perceived likelihood and impact; and
- to plan adaptation strategies to minimise such threats to health.

A suite of research activities was undertaken to meet these objectives, which align with the themes of the research. The research questions and methods are elaborated in Chapter 3.

It should be noted that all of the research work contained in this thesis, including the publications, is in addition to the reports routinely compiled by WHO for the regional project on health vulnerability and adaptation assessments. In other words, this thesis provides invaluable added value in the research and academic domains which goes substantially beyond the operational work conducted as part of the underlying WHO project to which this research was linked.

In terms of the geographic scope of the project, it is acknowledged that not all PICs could be included, for various reasons. Papua New Guinea, for example, had already undertaken a health vulnerability and adaptation assessment in 2010. The French territories, including French Polynesia, New Caledonia and Wallis and Futuna, had separate support for related work from the Secretariat for the Pacific Community. Other small territories such as Tokelau, Commonwealth of the Northern Mariana Islands and Pitcairn Island, affiliated with New Zealand, the USA and UK respectively, are yet to receive dedicated support for health adaptation, but must not be overlooked as this work continues.

1.4 Thesis structure

This thesis is composed of a series of published works that address the three key themes above. The journal papers and textbook chapters included constitute the most comprehensive overview of climate change and health in the Pacific region to date. These were complemented by a WHO report entitled *Human Health and Climate Change in Pacific Island Countries*, published in late 2015, of which I am lead author.

The thesis also contains sections on methods, discussion points and conclusions that link the published papers together into a coherent body of work.

The outline of the thesis is as follows:

Chapter Two gives an overview of climate change and health theory, with a focus on the work of WHO and the Intergovernmental Panel on Climate Change (IPCC) in determining global and regional health vulnerabilities and proposing methods for carrying out such assessments.

Chapter Three describes the methods employed in this research and compares the approaches taken in different countries involved in this project.

Chapter Four provides an overview of the processes, outcomes and implications of the WHO-supported climate change and health projects conducted in the Pacific between 2011 and 2015. This paper sets the scene for the country-specific papers that follow.

In Chapters Five, Six and Seven, three papers are presented which describe the distinct approaches employed in the climate change and health vulnerability assessment and adaptation planning processes in three different Pacific island countries – FSM, Vanuatu and Kiribati.

Chapters Eight and Nine focus on Fiji, with linked papers published two years apart – both in the *Fiji Journal of Public Health* – describing the disease-oriented approach to vulnerability and adaptation in that country, which was one of seven to participate in a WHO-led, GEF-funded global climate change and health pilot project.

The paper in Chapter Ten illuminates an unprecedented convergence of health risks in the Pacific, as climate change has the potential to act in synergy with non-communicable diseases (particularly diabetes) to increase the risk of communicable diseases such as tuberculosis – a disease not hitherto considered in the literature to be “climate-sensitive”. Chapter Eleven provides a regional, historical perspective on health systems governance as it applies to climate change adaptation. This paper places health adaptation in the context of the “Healthy Islands” vision – the overarching policy framework for health systems in the Pacific.

Chapters Twelve and Thirteen conclude the thesis with discussion of the research findings, synthesis of the implications and recommendations arising from the work contained therein.

Annex 1 is a chapter published in a textbook dedicated to Tony McMichael, one of the leaders of the field of climate change and health research, and one of the supervisors of my PhD until his death in 2013. This publication describes some of Tony’s outstanding contributions to the field of climate change and health and places his pioneering work in the context of the Pacific regional project.

All papers included in this thesis were prepared during the period of doctoral candidature, and are reproduced with the permission of the co-authors and respective publishing companies.

References

- 1 Mahany MJ, Keim ME. Challenges and Strategies for Climate Change Adaptation Among Pacific Island Nations. *Disaster Med Public Health Prep* 2011; published online June 30, 2011: 1–9.
- 2 Field C, Barros V, Stocker T, Qin D. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. Cambridge: Cambridge University Press, 2012
DOI:10.1017/CBO9781139177245.
- 3 Woodward A, Hales S, Litidamu N, Phillips D, Martin J. Protecting human health in a changing world: the role of social and economic development. *Bull World Health Organ* 2000; **78**: 1148–55.
- 4 World Meteorological Organization and the United Nations Environment Program 1988. Developing policies for responding to climatic change – a summary of the discussions and recommendations of the workshops held in Villach (28 September–2 October 1987) and Bellagio (9–13 October 1987) under the auspices of the Beijer Institute, Stockholm, Sweden (WMO/TD –225, April 1988).
- 5 McIver L, Hanna E. Fragile Paradise - Health and Climate Change in the South Pacific. In: Health of People, Places and Planet. Butler, Dixon & Capon (eds); ANU e-press 2015: 337–50.
- 6 World Health Organization, Western Pacific Regional Office. Regional Framework for Action to Protect Human Health from Effects of Climate Change in the Asia-Pacific Region. WHO 2007; 1-3. Manila, Philippines.
- 7 World Health Organization and Secretariat for the Pacific Community. Madang Commitment. 2009. WHO, Geneva, Switzerland.

Chapter Two

Background

2.1 Climate change – a global perspective

Since the late nineteenth century, it had been recognised that the Earth's average ambient temperature was increasing, and it was suspected that this was closely correlated with atmospheric carbon dioxide concentrations.¹ The two key features that distinguished this modern period of warming from earlier planetary climate cycles were the rate of temperature rise and the identification of a sudden acceleration around the time of the Industrial Revolution, which has continued over the last century (Figure 2.1).

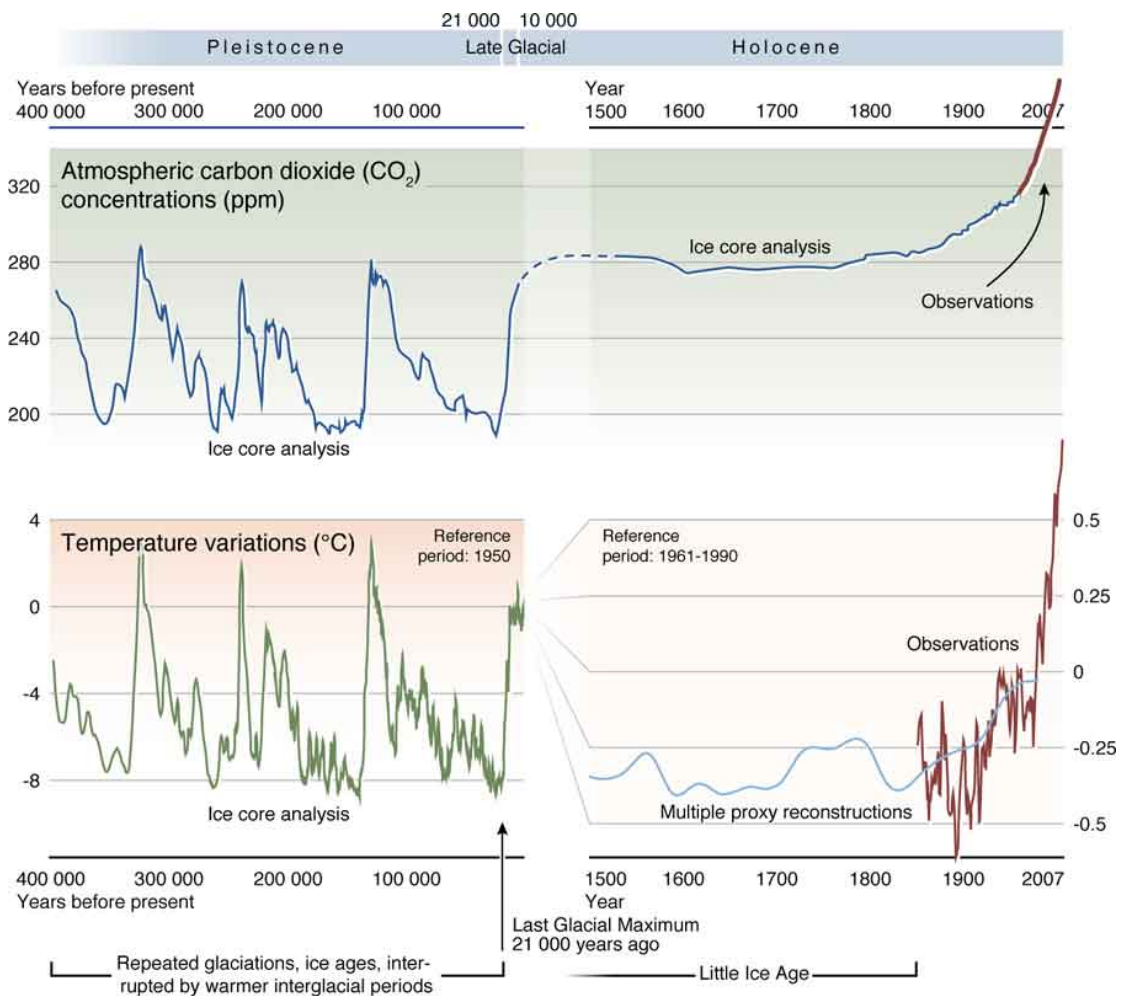


Figure 2.1 Historical global atmospheric carbon dioxide concentrations (top) and ambient temperatures (bottom). *Source:* Reproduced with permission from GRID-Arendal (http://www.grida.no/graphicslib/detail/historical-trends-in-carbon-dioxide-concentrations-and-temperature-on-a-geological-and-recent-time-scale_a210)

The combination of carbon dioxide and other heat-trapping (“greenhouse”) gases in the atmosphere, such as methane, has multiple, complex effects on hydro-meteorological systems. These effects manifest as detectable variations in weather (short-term) and climate (long-term), which are collectively known as “climate change” and are acknowledged to be the consequence of human activity (i.e. anthropogenic) – hence the introduction of the term “anthropocene” to describe the modern era.^{2,3}

The IPCC, in its Fifth Assessment Report (2013), documents the main categories of climate-related phenomena for which changes have been recorded since modern measurements began (approximately mid-twentieth century), along with an assessment of the contribution of human activity to these changes, and the likelihood of further changes over the course of the twenty-first century. These findings are summarised in Table 2.1 below.

Table 2.1 Global climate change phenomena. *Source:* Adapted from IPCC, 2013⁴

Phenomenon and direction of trend	Assessment of human contribution to observed changes	Likelihood of further changes this century
Warmer and/or fewer cold days and nights over most land areas	Very likely	Virtually certain
Warmer and/or more frequent hot days and nights over most land areas	Very likely	Virtually certain
Increased frequency and/or duration of heat waves over most land areas	Likely	Very likely
Heavy precipitation events - increase in the frequency, intensity, and/or amount of heavy precipitation	Medium confidence	Very likely
Increased incidence and/or magnitude of extreme high sea level	Likely	Very likely
Increases in intensity and/or duration of drought	Low confidence	Likely
Increases in intense tropical cyclone activity	Low confidence	More likely than not

2.2 Climate change in the Pacific

In the Pacific, a regional technical collaboration between the Commonwealth Scientific Industrial and Research Organisation, Australian Bureau of Meteorology and meteorology departments from over a dozen PICs, known as the Pacific Climate Change Science and Adaptation Program (PCCSP), published a series of scientific reports in 2011 providing detailed climate change observation and projection information for all countries in the region. The major climate change phenomena predicted for the Pacific region through the work of PCCSP are summarised in Table 2.2.

Table 2.2 Pacific climate change phenomena. *Source:* Adapted from PCCSP, 2011⁵

Climate change phenomenon	Expected change in Pacific region
Increasing air temperature	Increase by up to 1°C by 2030 and 3°C by 2090, with large increases in incidence of heat waves and extremely hot days and nights
Increasing sea-surface temperature	Increase across region, maximal in central equatorial Pacific
Altered rainfall patterns	Increase in total annual rainfall, heavy rainfall days and frequency and severity of extreme rainfall events (with flooding potential)
Humidity	Little overall change due to increase in both production of water vapour and potential atmospheric water vapour-holding capacity
Evapotranspiration	Increase in several areas with potential for resulting increased aridity
Sea-level rise	0.55-1.0m increase by 2100
Ocean acidification	Increase across region

The effects of sea-level rise, particularly in combination with increased storm surges, in terms of the immediate physical hazards and the loss of land and livelihoods that entails, are visible, tangible and literally life-threatening realities for Pacific island communities. Climate change poses an existential threat for the atoll countries of Kiribati, Marshall Islands and Tuvalu, where the vast majority of the population live in overcrowded conditions less than two metres above sea level. Tuvalu's former Prime Minister, Bikenibeu Paeniu has reflected that "...in my grandchildren's lifetime, maybe even earlier, they may not have a nation to live in... Sooner or later, Tuvalu will eventually be submerged underwater"¹.

¹ Interview for "New Flags Flying – Pacific Leadership" series, Radio New Zealand, 2011.

2.3 Impact, risk and vulnerability

In exploring and attempting to explain the human dimensions of the consequences of climate change, terms that are used in the literature include impact, risk and vulnerability. The IPCC definitions of these terms are provided here,⁶ as the sense in which they will be applied in this thesis. In doing so, it is acknowledged that many alternative definitions of vulnerability make explicit recognition of other contributing factors, particularly those in the socio-economic and development domains, which are also linked to health. Nevertheless, for clarity and coherence, the IPCC definition will be the definition referenced in this thesis.

Impact: An effect on natural and human systems; in particular, effects on lives, livelihoods, health status, ecosystems, economic, social and cultural assets, services and infrastructure due to the interaction of climate changes or hazardous climate events.

Risk: The potential for consequences where something of human value (including humans themselves) is at stake and where the outcome is uncertain.

Vulnerability: The propensity or predisposition to be adversely affected; this encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.

These distinct but related terms overlap with other concepts such as exposure and hazard, as depicted in Figure 2.2.

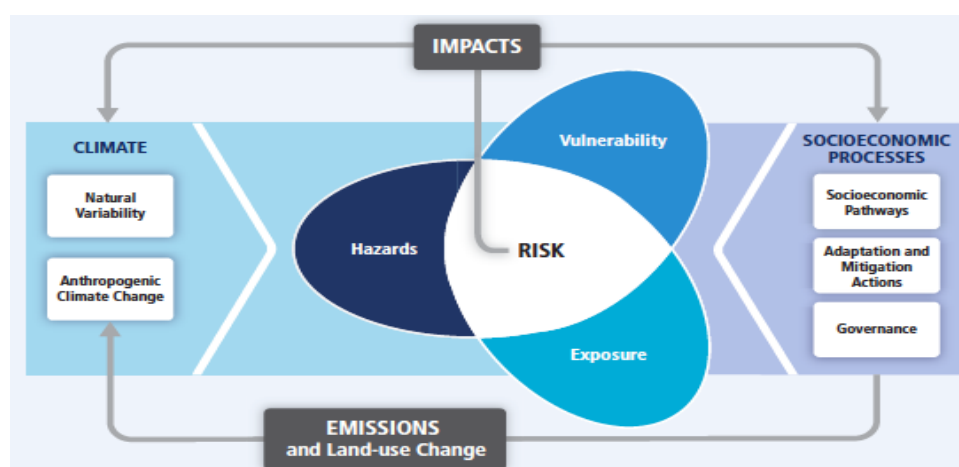


Figure 2.2 The intersecting concepts of hazard, exposure, vulnerability, risk and impact

Source: IPCC, 2014⁷

2.4 Health impacts of climate change

The impacts of climate change on human health range from the immediate and obvious to the insidious and obscure. A paradigm used by many, including the IPCC, to consider and explain these effects, is to describe them in terms of their mechanism and directness of action, for example: direct, indirect and diffuse; or primary, secondary and tertiary (see Table 2.2).⁸⁻¹⁰

Table 2.2 Climate change and health exposure-impact pathways

Impact category	Examples of impact pathways and consequences
Primary	Direct biological consequences of heat waves (e.g. cardio-respiratory arrests); traumatic injuries and deaths from extreme weather events such as cyclones
Secondary	Changes in biophysically and ecologically based processes and systems, particularly food yields, water flows and the range and behaviors of vectors such as mosquitoes, causing increases in diseases such as malaria, dengue fever and diarrhoeal disease
Tertiary	Loss of land and livelihoods, population displacement and conflict leading to mental health disorders and social dysfunction.

These effects may be moderated by efforts to minimise exposure, vulnerability and risk, which in the context of climate change are known as adaptations.^{6,11}

Throughout the first decade of this century, as increased attention was paid to the risks posed by climate change on health and the evidence basis expanded,¹²⁻¹⁶ the list of diseases and categories of ill-health considered sensitive to climate change grew steadily. WHO developed models for estimating climate change-attributable burdens of diseases,¹⁷ and included climate change in its quantitative assessments of the global causes of illness and death.^{18,19} The latest of these, published in 2014, projects that the annual excess mortality due to climate change around the year 2030 will be approximately 250 000 deaths, taking into account only the burden of additional heat-related illness, diarrhoeal disease, malaria and malnutrition.¹⁹

The IPCC has described what it sees as the main categories of climate-sensitive health risks, and provided levels of confidence with which these burdens of disease are predicted to increase due to climate change. These effects and predictions are summarised in Table 2.3.

Table 2.3 Summary of the anticipated global health impacts of climate change, with confidence levels. *Source:* Adapted from IPCC, 2014¹⁰

Health impact	Confidence rating
Greater risk of injury, disease and death due to heat waves and extreme weather events such as fires, floods and tropical storms	Very high
Increased risks of food- and water-borne diseases	Very high
Increased risk of under-nutrition (resulting from diminished food production in poor regions)	High
Increased risk of vector-borne diseases	Medium
Modest improvements in cold-related morbidity and mortality	Low

2.5 Climate change and health in the Pacific region

The literature on climate change and health in the Pacific prior to 2010 is, broadly speaking, limited to that inferred from the work of the IPCC and other studies related to small island states;^{20,21} hypothesised based on the climate change research conducted in the Pacific (but not specific to health);²²⁻²⁴ included in health vulnerability assessments for the wider Asia-Pacific²⁵ and Oceania²⁶ regions; or extrapolated from country-specific studies, such as the preliminary assessment in Samoa.²⁷

The small number of notable publications from this period that specifically addressed health and climate change in Pacific island countries²⁸⁻³⁰ were based and informed speculation, without recourse to in-country research, as had been the case for the early work on climate change and health on a global scale in the 1990s.³¹ These publications were thus largely restricted to generalities, such as pointing out the potential risks to Pacific communities of increasing food-, water- and vector-borne diseases; extreme weather events; and malnutrition, without linking these with empirical data or providing estimates of future climate change-attributable burdens of disease. However, despite their limitations, these early reports laid the foundation for subsequent health vulnerability assessments, and made clear the need for strong governance mechanisms to enable effective adaptation.²⁸

2.6 Rationale for this research

By 2010, with the aforementioned regional climate change and health mandates in place,^{32,33} there was consensus regarding the urgent need to carry out national climate change and health vulnerability assessments and plan adaptation strategies for all countries in the Pacific region. With WHO having led the establishment of general principles and evidence-based guidelines for these processes,^{34,35} this project commenced in late 2010, with the following overarching objective: “To strengthen country-level capacities with respect to research and policy-making relevant to climate change and health, by supporting vulnerability assessments, data collection and analysis, and preparation of draft national action plans for climate change and health in Pacific island countries”.

The work presented in this thesis represents the research that was woven through this regional project, providing the evidence basis for the findings and adaptation plans for each country and the region as a whole.

The research components of the project, led by the author as a doctoral programme of work, thus sought to address the following critical gaps in knowledge regarding climate change and health in the Pacific that existed prior to commencement of the project and the author’s related PhD:

- Comparative analysis of the optimal methods of assessing health vulnerability and adaptation strategies in the severely resource-constrained environments in Pacific island countries;
- Identification of the risks to health posed by climate change for individual Pacific island countries and the region as a whole, as determined by quantitative and qualitative vulnerability assessment techniques; and
- Establishment of priorities for health systems adaptations to protect human health from climate change in the region.

References

- 1 Arrhenius S. On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground. *Philos Mag J Sci* 1896; **5**: 237–76.
- 2 Steffen W, Grinevald J, Crutzen P, McNeill J. The Anthropocene: conceptual and historical perspectives. *Philos Trans A Math Phys Eng Sci* 2011; **369**: 842–67.
- 3 McMichael a. J. Population health in the Anthropocene: Gains, losses and emerging trends. *Anthr Rev* 2014; **1**: 44–56.
- 4 IPCC, 2013: 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 [Stocker, TF *et al* (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- 5 Australian Bureau of Meteorology and Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2011). *Climate change in the Pacific: Scientific assessment and new research*. Volume 1: Regional Overview. Melbourne, Australia.
- 6 Allwood J.M., V. Bosetti, N.K. Dubash, L. Gómez-Echeverri, and C. von Stechow, 2014: Glossary. In: *Climate Change 2014: Mitigation of Climate Change*. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O, *et al* (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- 7 IPCC, 2014: Summary for policymakers. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, CB, *et al* (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.
- 8 McMichael AJ, Lindgren E. Climate change: present and future risks to health, and necessary responses. *J Intern Med* 2011; **270**: 401–13.
- 9 Butler CD, Harley D. Primary, secondary and tertiary effects of eco-climatic change: the medical response. *Postgrad Med J* 2010; **86**: 230–4.
- 10 Smith, K.R., A.Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, and R. Sauerborn, 2014: Human health: impacts, adaptation, and co-benefits. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, CB, *et al* (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 709-754.
- 11 Chalabi Z, Kovats S. Tools for developing adaptation policy to protect human health. *Mitig Adapt Strateg Glob Chang* 2014; **19**: 309–30.
- 12 McMichael AJ, Woodruff RE, Hales S. Climate change and human health: present and future risks. *Lancet* 2006; **367**: 859–69.

- 13 Haines A, Kovats RS, Campbell-Lendrum D, Corvalan C. Climate change and human health: Impacts, vulnerability and public health. *Lancet* 2006; **367**: 2101–9.
- 14 Weiss R, McMichael A. Social and environmental risk factors in the emergence of infectious diseases. *Nat Med* 2004; **10**: S70–6.
- 15 Githeko a K, Lindsay SW, Confalonieri UE, Patz J a. Climate change and vector-borne diseases: a regional analysis. *Bull World Health Organ* 2000; **78**: 1136–47.
- 16 World Health Organization. Climate change and human health – risks and responses. WHO, 2004; Geneva, Switzerland.
- 17 Campbell-Lendrum D, Woodruff R. Comparative Risk Assessment of the Burden of Disease from Climate Change. *Environ Health Perspect* 2006; **114**: 1935–41.
- 18 Patz J., Gibbs HK, Foley J., Rogers J V., Smith KR. Climate Change and Global Health: Quantifying a Growing Ethical Crisis. *Ecohealth* 2007; **4**: 397–405.
- 19 World Health Organization. Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. WHO, 2014; Geneva, Switzerland.
- 20 Ebi KL, Lewis ND, Corvalan C, Lucia S. Climate Variability and Change and Their Potential Health Effects in Small Island States : Information for Adaptation Planning in the Health Sector. *Environ Health Perspect* 2006; **114**: 1957–63.
- 21 Nurse, L.A., R.F. McLean, J. Agard, *et al*, 2014: Small islands. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, VR, *et al*, (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1613-1654.
- 22 Mimura N. Vulnerability of island countries in the South Pacific to sea level rise and climate change. *Clim Res* 1999; **12**: 137–43.
- 23 Barnett J, Campbell J. Climate Change and Small Island States: Power, Knowledge, and the South Pacific. Earthscan, 2010.
- 24 Pacific Islands Framework for Action on Climate Change, Climate Variability and Sea Level Rise 2000-2004. 2006; 1–10.
- 25 Woodward A, Hales S, Weinstein P. Climate change and human health in the Asia Pacific region: who will be most vulnerable? *Clim Res* 1998; **11**: 31–8.
- 26 McMichael A, Woodruff R, Whetton P, *et al*. Human health and climate change in Oceania: a risk assessment. Commonwealth of Australia, 2002; Canberra, Australia.
- 27 Lindsay G, Percival T, Woodward A. From typhoid to tsunamis: Samoan children in a changing world. *Int Pub Health J* 2010; **2**(4): 447-458.
- 28 Lovell SA. Health governance and the impact of climate change on Pacific small island developing states. *IHDP Updat* 2011; : 50–5.

- 29 Woodward A, Hales S, Litidamu N, Phillips D, Martin J. Protecting human health in a changing world: the role of social and economic development. *Bull World Health Organ* 2000; **78**: 1148–55.
- 30 Russell L. Poverty, climate change and health in Pacific island countries: Issues to consider in discussion, debate and policy development. Center for Australia and New Zealand Studies, Georgetown University, 2011; Washington D.C., USA.
- 31 World Meteorological Organisation, World Health Organization and the United Nations Development Programme. *Climate and Human Health*. WMO, 1996; Geneva, Switzerland.
- 32 World Health Organization, Western Pacific Regional Office. Regional Framework for Action to Protect Human Health from Effects of Climate Change in the Asia-Pacific Region. WHO, 2007; 1–4.
- 33 World Health Organization and Secretariat for the Pacific Community. Madang Commitment. 2009; Manila, Philippines.
- 34 Kovats R, Ebi K, Menne B. Methods of assessing human health vulnerability and public health adaptation to climate change. WHO, 2003; Copenhagen, Denmark.
- 35 Ebi KL, Kovats RS, Menne B. An Approach for Assessing Human Health Vulnerability and Public Health Interventions to Adapt to Climate Change. *Environ Health Perspect* 2006; 114(12): 1930–1934.

Chapter Three

Research Design

3.1 Key research questions

The key research questions for this PhD were as follows:

1. What methods may be used to assess climate change and health vulnerabilities in the Pacific, and how do these methods compare in terms of their focus, feasibility, usefulness and relevance to Pacific island countries?
2. What are the most significant risks to health posed by climate change in the Pacific region?
3. What are the main opportunities and challenges in terms of implementing effective climate change and health adaptation strategies in Pacific island countries?

These key questions – necessarily broad in scope – were addressed by the author over the duration of the climate change and health project conducted by WHO in the Pacific via a three-phase process involving collection of data, assessment of vulnerabilities and planning of adaptation strategies to minimise the health impacts of climate change in the region.

- The first phase involved inception workshops, which brought together country representatives and consultant teams to review the current state of knowledge on climate change and health, and discuss vulnerabilities and approaches to adaptation relevant to each country.
- During the second phase, the international support teams visited each of the countries for further stakeholder consultations, examination and analysis of the available local data on climate and climate-sensitive diseases, and prioritisation of climate-sensitive health risks. Stakeholders in this process included government and nongovernment agencies, community representatives and the private sector.
- In the final phase, during return visits to each country, WHO teams assisted the country teams in drafting national climate change and health action plans that reflected key vulnerabilities and adaptation priorities with respect to the country-specific health impacts of climate change.

The research methods involved in each of these three phases are elaborated in turn below.

3.2 Assessing vulnerability

The process recommended by WHO to assess health vulnerabilities to climate change is well articulated in the literature,^{1,2} and is generally considered to involve the following steps:

- determining the scope of the assessment;
- describing the current distribution and burden of climate-sensitive diseases;
- identifying and describing current strategies, policies and measures that reduce the burden of climate-sensitive diseases;
- reviewing the health implications of the potential impact of climate change and variability on other (non-health) sectors;
- estimating the future potential health impact using scenarios of future climate change, population growth and other factors, and describing the related uncertainty; and
- assembling the results and drafting a scientific assessment report.

The processes outlined above are intended to be placed within the broader health policy landscape, and include feedback loops that inform adaptation planning and enable evaluation. These links are depicted in Figure 3.3.

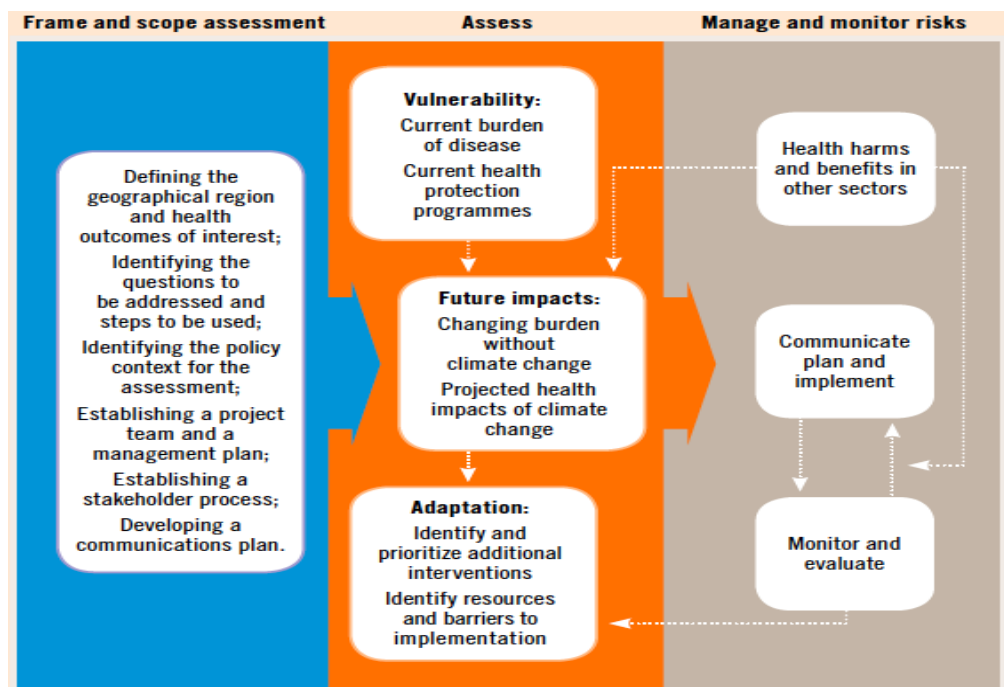


Figure 3.3 Overview of the climate change and health vulnerability assessment process.

Source: Based on Kovats et al, 2003¹

A detailed comparison between the WHO vulnerability assessment and adaptation planning framework and the process implemented in the Pacific regional project is provided in the following chapter.

WHO has also provided guidance on the statistical techniques that may be used to estimate the burdens of ill-health attributable to climate change in present and future periods.^{3,4} This requires complete and reliable baseline data, and correlation of disease burdens (e.g. incidence) with climatic factors (e.g. temperature or rainfall). These statistical associations are then extrapolated forward in time based on robust climate projection data. In its ideal form, this process also enables an estimation of the morbidity and mortality that may be avoided under various scenarios, such as mitigation (i.e. the arresting of climate change at a particular point in time).

Figure 3.4 shows the process by which such estimates may be made if the abovementioned data requirements are met.

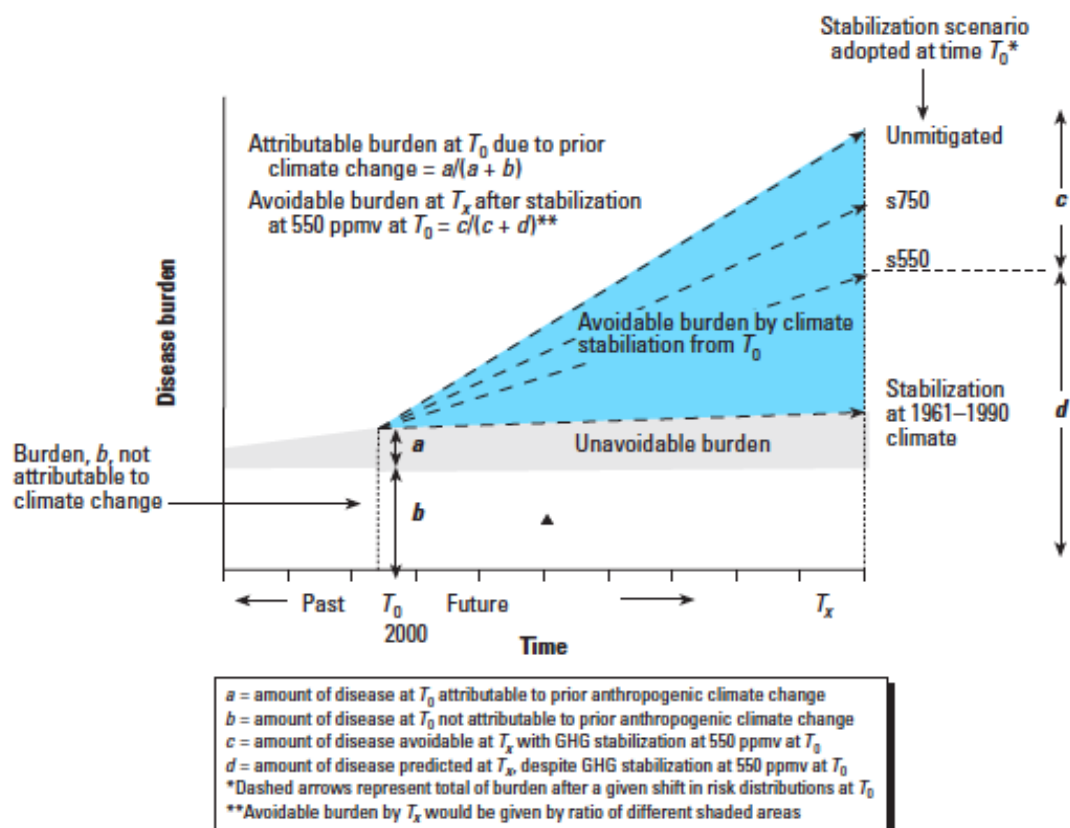


Figure 3.4 Estimating attributable and avoidable risk of disease burden(s) due to climate change

(GHG: greenhouse gases; ppmv: parts per million by volume; T: time)

Source: Campbell-Lendrum et al, 2006³

In the Pacific island countries included in this project, the highly variable (and often poor) availability, reliability and completeness of data typically prohibited the sophisticated attribution and projection modeling described in the WHO guidelines. Examples of the compromised quality of disease data included incomplete records; lack of confirmatory diagnostics – and thus reliance on case-based surveillance; and likely misclassifications (e.g. the inability to distinguish between causes of acute febrile illnesses such as dengue fever and leptospirosis, particularly in the setting of disasters and outbreaks). The quality of climate data across the region was often of a higher standard (in terms of its reliability and completeness), but rarely covered time periods long enough to enable the detection of statistically significant associations with variations in disease trends.

Some countries – notably FSM, Marshall Islands, Palau and Fiji – strove to use the best available data to construct climate-disease exposure-response models, and included these statistical analyses in their vulnerability assessments. The techniques employed to model climate-disease associations included time series analyses, Poisson regression and distributed lag non-linear modeling, along with spatial analysis for detection of “hotspots”, all of which have strong precedents in the literature for their use in this context.⁵⁻⁸ Examples of such quantitative models are provided for FSM and Fiji in this thesis.

In other Pacific island countries, a more qualitative approach was taken to the vulnerability assessment process. Specifically, a modified version of the Environmental Health Impact Assessment (EHIA) framework, adapted for use in the climate change context⁹ and piloted successfully in Australia,¹⁰ was employed in the vulnerability assessments for Solomon Islands, Vanuatu and Nauru. This highly iterative and consultative approach, which considers various aspects of vulnerability from across society and policy areas, was particularly useful in the Pacific island country context,¹¹ given the frequent absence of sufficiently robust data available for quantitative analysis. The steps involved in this modified EHIA approach, as it was carried out in Vanuatu, are described in Chapter Six.

The approach taken in each Pacific island country was determined by the availability of relevant data and the preference of the national team, as well as the analytical methods considered most appropriate for each country’s context. These are presented in detail in the following chapters.

3.3 Prioritising risk

A critical feature of the vulnerability assessments conducted in the Pacific – as elsewhere – was the consideration of the range of plausible hazards posed by climate change on health and the stratification of these according to the level of risk represented. Levels of risk were determined as a function of each hazard’s likelihood and consequence (the latter may, in this context, be considered synonymous with “impact”), as it was perceived to pertain to each country. This approach has its historical roots in risk assessment theory,¹² and has for decades been applied to policy development in the fields of environment,¹³ health¹⁴ and, more recently, climate change and health.¹⁵

The risk stratification process is further elaborated in Chapter Four and examples of country-specific outcomes are presented in Chapter Five (for FSM) and Chapter Six (Vanuatu).

3.4 Planning adaptation

Adaptation strategies for each PIC were planned according to the outcomes of the respective vulnerability assessment and risk stratification processes – see Chapter Four.

Some of the key characteristics of climate change and health work in the Pacific mentioned above – for example, the variations in inter-country methodologies and inconsistencies in data availability – meant that the adaptation planning process generally favoured a “no/low regrets” approach. In practice, this meant that the national plans for health adaptation aimed to increase the capacity of the health system, and society more broadly, to manage climate risks with a view to reducing climate change and health vulnerabilities while increasing the opportunities for sustainable development.¹⁶

Thus, Pacific island countries followed a highly pragmatic approach to adaptation that sought to strengthen health systems resilience and capacity to meet contemporary challenges, as well as the longer-term hazards posed by climate change. This is consistent with the approach recommended for weak health systems, such as those in the small island developing states of the Pacific.¹⁷ The main advantages of this approach are discussed in more detail in Chapter Eleven, and some critical limitations explored in Chapter Twelve.

References

- 1 Kovats R, Ebi K, Menne B. Methods of assessing human health vulnerability and public health adaptation to climate change. *Pan Am Health* 2003. <http://researchonline.lshtm.ac.uk/14942/> (accessed Nov 7, 2012).
- 2 Ebi KL, Kovats RS, Menne B. An Approach for Assessing Human Health Vulnerability and Public Health Interventions to Adapt to Climate Change. *Environ Health Perspect* 2006; **114**: 1930–4.
- 3 Campbell-Lendrum D, Woodruff R. Comparative Risk Assessment of the Burden of Disease from Climate Change. *Environ Health Perspect* 2006; **114**: 1935–41.
- 4 Kovats RS, Campbell-Lendrum D, Matthies F. Climate change and human health: estimating avoidable deaths and disease. *Risk Anal* 2005; **25**: 1409–18.
- 5 Bhaskaran K, Gasparrini A, Hajat S, Smeeth L, Armstrong B. Time series regression studies in environmental epidemiology. *Int J Epidemiol* 2013; **42**: 1187–95.
- 6 Hashizume M, Armstrong B, Hajat S, *et al.* The Effect of Rainfall on the Incidence of Cholera in Bangladesh. *Epidemiology* 2008; **19**: 103–10.
- 7 Gasparrini A, Leone M. Attributable risk from distributed lag models. *BMC Med Res Methodol* 2014; **14**: 55.
- 8 Lover A, Buchy P, Rachline A, *et al.* Spatial epidemiology and climatic predictors of paediatric dengue infections captured via sentinel site surveillance, Phnom Penh Cambodia 2011-2012. *BMC Public Health* 2014; **14**: 658.
- 9 Brown H, Spickett J, Katscherian D. A health impact assessment framework for assessing vulnerability and adaptation planning for climate change. *Int J Environ Res Public Health* 2014; **11**: 12896–914.
- 10 Spickett JT, Brown HL, Katscherian D. Adaptation strategies for health impacts of climate change in Western Australia: Application of a Health Impact Assessment framework. *Environ Impact Assess Rev* 2011; **31**: 297–300.
- 11 Spickett JT, Katscherian D. Health Impacts of Climate Change in the Solomon Islands: An Assessment and Adaptation Action Plan. *Glob J Health Sci* 2014; **6**: 261–73.
- 12 Wilson R, Crouch E a. Risk assessment and comparisons: an introduction. *Science* 1987; **236**: 267–70.
- 13 Russell M, Gruber M. Risk assessment in environmental policy-making. *Science* 1987; **236**: 286–90.
- 14 Lave LB. Health and safety risk analyses: information for better decisions. *Science* 1987; **236**: 291–5.

- 15 Brown H, Spickett J. Health Consequence Scales for Use in Health Impact Assessments of Climate Change. *Int J Environ Res Public Health* 2014; **11**: 9607–20.
- 16 Heltberg R, Siegel PB, Jorgensen SL. Addressing human vulnerability to climate change: Toward a ‘no-regrets’ approach. *Glob Environ Change* 2009; **19**: 89–99.
- 17 Wardekker JA, de Jong A, van Bree L, Turkenburg WC, van der Sluijs JP. Health risks of climate change: An assessment of uncertainties and its implications for adaptation policies. *Environ Health* 2012; **11**: 67.

Chapter Four

Paper 1: Health impacts of climate change in Pacific island countries: a regional assessment of vulnerabilities and adaptation priorities

Prelude

This chapter summarises the Pacific regional climate change and health project in terms of its processes, outcomes and implications. The focus is on the methods and results of the vulnerability assessments carried out across the region, linked with the priority adaptation strategies planned in Pacific island countries.

It is the most up-to-date and comprehensive synthesis of knowledge regarding climate change and health in the Pacific, and complements the forthcoming WHO report entitled “Human Health and Climate Change in Pacific Island Countries”, compiled by the same authors, published in late 2015.

This paper references the other published works included in this thesis, thus incorporating the country-specific components of the regional project, and also describes the common themes to have emerged from the vulnerability assessments and adaptation planning processes throughout the region.

The candidate’s estimated proportional contributions to this paper were as follows:

Research design:	70%
Analysis and interpretation:	80%
Authorship of paper:	90%

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Health Impacts of Climate Change in Pacific Island Countries: A Regional Assessment of Vulnerabilities and Adaptation Priorities

Lachlan McIver,^{1,2} Rokho Kim,² Alistair Woodward,³ Simon Hales,⁴ Jeffery Spickett,⁵
Dianne Katscherian,⁵ Masahiro Hashizume,⁶ Yasushi Honda,⁷ Ho Kim,⁸ Steven Iddings,²
Jyotishma Naicker,² Hilary Bambrick,⁹ Anthony J. McMichael^{1*}, and Kristie L. Ebi¹⁰

¹National Centre for Epidemiology and Population Health, Australian National University, Canberra, Australia; ²World Health Organization, Western Pacific Regional Office, Division of Pacific Technical Support, Suva, Fiji; ³School of Public Health, University of Auckland, Auckland, New Zealand; ⁴Department of Public Health, University of Otago, Wellington, New Zealand; ⁵World Health Organization Collaborating Centre for Environmental Health Impact Assessment, Curtin University, Perth, Australia; ⁶Institute of Tropical Medicine, Nagasaki University, Nagasaki, Japan; ⁷Faculty of Health and Sport Science, University of Tsukuba, Tsukuba, Japan; ⁸Graduate School of Public Health, Seoul National University, Seoul, Republic of Korea; ⁹Centre for Health Research, School of Medicine, University of Western Sydney, Sydney, Australia; ¹⁰School of Public Health, University of Washington, Seattle, USA. *Professor Tony McMichael passed away in 2014.

Address correspondence to Lachlan McIver, National Centre for Epidemiology and Population Health, Australian National University, Canberra, A.C.T., 2601. Telephone: +61 3 9421 6754. E-mail: lachlan.mciver@gmail.com

Running title: Health and climate change in the Pacific region

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Abstract

Background: Between 2010 and 2012, the World Health Organization Division of Pacific Technical Support led a regional climate change and health vulnerability assessment and adaptation planning project, in collaboration with health sector partners, in thirteen Pacific island countries - Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu.

Objective: To assess the vulnerabilities of Pacific island countries to the health impacts of climate change and plan adaptation strategies to minimize such threats to health.

Methods: This assessment involved a combination of quantitative and qualitative techniques. The former included descriptive epidemiology, time series analyses, Poisson regression and spatial modeling of climate and climate-sensitive disease data, in the few instances where this was possible; the latter included wide stakeholder consultations, iterative consensus-building and expert opinion. Vulnerabilities were ranked using a “likelihood versus impact” matrix, and adaptation strategies prioritized and planned accordingly.

Results: The highest priority climate-sensitive health risks in Pacific island countries include trauma from extreme weather events; heat-related illnesses; compromised safety and security of water and food; vector-borne diseases; zoonoses; respiratory illnesses; psychosocial ill-health; non-communicable diseases; population pressures and health system deficiencies. Adaptation strategies relating to these climate change and health risks can be clustered according to categories common to many countries in the Pacific region.

Conclusion: Pacific island countries are among the most vulnerable in the world to the health impacts of climate change. This vulnerability is a function of their unique geographic, demographic and socioeconomic characteristics, combined with their exposure to changing weather patterns associated with climate change, the health risks entailed, and the limited capacity of the countries to manage and adapt in the face of such risks.

Introduction

Climate change is widely acknowledged as one of the most serious global threats to future human population health and international development (Costello et al. 2009; Stephenson et al. 2013; Woodward et al. 2014). The Fifth Assessment Report (AR5) from the Intergovernmental Panel on Climate Change (IPCC) affirms that recent decades have seen warming air and ocean temperatures; altered precipitation patterns; changes in the frequency and intensity of some extreme events such as droughts, floods and storms; and rising sea levels (Field et al. 2014). The AR5 also asserts with greater confidence that recent warming is largely attributable to human activity than reported by the assessment published in 2007 (Parry et al. 2007). Further, there is increasing certainty these trends will continue or, in some cases, accelerate (Field et al. 2014).

A changing climate has significant and diverse impacts on human health (McMichael and Lindgren 2011; Woodward et al. 2014). The pathways by which climate change affects health vary according to their modes of action and include primary or direct effects (e.g. injuries and deaths caused by extreme weather events such as cyclones); secondary or indirect effects (e.g. the increasing geographic range of, and population exposed to, vectors that spread disease); and tertiary, diffuse and/or delayed effects (e.g. disruptions to health and social services) (Butler and Harley 2010; McMichael 2013).

Pacific island countries (PICs) are among those most vulnerable to the health impacts of a changing climate (Hanna and McIver 2014; Woodward et al. 2000). This vulnerability is a function of their exposure to changing weather patterns associated with climate change, the health risks entailed, and the limited capacity of the countries to manage and adapt in the face of such risks. The climate change phenomena occurring in the Pacific pose a suite of health hazards to the island communities across the region. A conceptualization of the pathways by

which climate change will affect health in the Pacific and the major anticipated impacts throughout the region is shown in Figure 1.

In PICs, this vulnerability reflects the unique geographic, demographic and socio-economic characteristics of small island developing states (SIDS) (Table 1) which, combined with their contemporary burden of ill-health and relatively low health systems capacity, give credence to their epithet of “canaries in the coalmine” of climate change and health (Hanna and McIver 2014).

Recognizing the risks to health posed by climate change, the WHO Regional Offices for the Western Pacific and South-East Asia issued a joint *Regional Framework for Action to Protect Human Health from the Effects of Climate Change in the Asia-Pacific Region* (WHO 2007). This Framework committed all countries in the region to increasing awareness of climate change and health; strengthening the capacity of health systems to protect against climate-related health risks and reduce greenhouse gas emissions in the health sector; and ensuring that health concerns were addressed in climate action in other sectors. Specific actions mandated in the Framework included supporting formalized climate change and health vulnerability assessments, and leading the health sector’s contribution to national adaptation planning processes in the region.

Subsequently, the health ministers of PICs strengthened their commitments to action on climate change at their biennial meeting in Madang, Papua New Guinea, in 2009. The *Madang Commitment* included further recommendations related to vulnerability assessments and adaptation planning, framing these within the *Healthy Islands* vision for health systems development in the Pacific (Galea et al. 2000; WHO 2009).

This paper describes the process and outcomes of climate change and health vulnerability assessments in thirteen SIDS in the Pacific region: Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Marshall Islands, Nauru, Niue, Palau, Samoa, Solomon Islands, Tonga, Tuvalu and Vanuatu (see map in Figure 2).

The paper reports how these assessments link with adaptation planning; highlights some of the unique challenges facing PICs in the context of climate change; and summarizes the corresponding recommendations arising from the regional project. This paper is aimed at a general scientific audience, and is a synthesis of the key technical findings and policy implications of the forthcoming WHO report entitled *Human Health and Climate Change in Pacific Island Countries* (McIver et al. 2015a).

Methods

Between 2010 and 2012, the WHO Division of Pacific Technical Support, with support from the Western Pacific Regional Office (WPRO) and funding from the governments of Republic of Korea and Japan, led a regional climate change and health vulnerability and adaptation project involving eleven PICs: Cook Islands, Federated States of Micronesia (FSM), Kiribati, Marshall Islands, Nauru, Niue, Palau, Solomon Islands, Tonga, Tuvalu and Vanuatu. This project was implemented in three phases, with the eleven countries divided into three groups on broadly geographic lines, and a team of expert climate change and health consultants guiding and assisting each group. These eleven countries form the majority of independent or autonomous states in the Pacific region, along with Fiji and Samoa, which carried out related projects (see below). Papua New Guinea has been involved in a separate climate change and health project, along with other countries in the Western Pacific region, so was not included; the French territories of New Caledonia, French Polynesia and Wallis and Futuna were excluded for similar reasons.

In the first phase, sub-regional inception meetings were held in Auckland, New Zealand (for the group that included Cook Islands, Kiribati, Niue, Tonga and Tuvalu); Honiara, Solomon Islands (for Nauru, Solomon Islands and Vanuatu); and Pohnpei, FSM (for FSM, Marshall Islands and Palau). During these meetings, the science of climate change and health was reviewed, along with the relevant work hitherto conducted in each country, and plans were laid for the in-country vulnerability assessment and adaptation planning phases of the project.

The second phase involved a mixed-methods approach to ascertain each country's climate-sensitive health risks, based on a combination of review and analysis of climate and health data; stakeholder consultations; and an assessment of the potential impacts of a changing climate across different aspects of society. Where possible, epidemiological analysis was carried out on the available data on historical climate variables and climate-sensitive diseases (e.g. diarrhoeal disease, dengue fever and leptospirosis). This was only possible in some countries, where the data was adequate (in terms of quality and quantity) and the technical support was available. The sophistication of the modeling undertaken ranged from simple reviews of disease burdens and weather patterns in Kiribati (McIver et al. 2014) to Poisson regression models in FSM (McIver et al. 2015b) and similar techniques, combined with spatial modeling, for multiple climate-sensitive diseases in Fiji (McIver et al. 2012). The results of these country-specific analyses have not been included in this paper, which instead provides a more general, regional overview.

In the final phase, each country's climate change and health vulnerabilities were assessed via a "likelihood-versus-consequence" matrix. This tool was used to rank climate-sensitive health priorities, rationalize resources, and focus the activities of the health sector on the most urgent adaptation activities. Its use was based on precedents in Australia (Brown et al. 2014) and growing evidence of its utility in this context in Pacific island countries such as Vanuatu

(Spickett and Katscherian 2014; Spickett et al. 2013). In the use of this matrix, each climate-sensitive health risk was considered in terms of the likelihood of the burden of disease increasing with climate change (over a twenty year time-frame), a range of climate change projections (as localized as possible), and the impact of such an increased health burden occurring (considering the resilience or coping capacity of the community and health sector to manage such consequences).

Each Pacific island country differed in terms of their willingness and perceived capacity to manage their respective highest-priority climate-sensitive health risks. Some elected to include most or all of these hazards in their adaptation plans; others chose to concentrate on the few health impacts deemed to represent the greatest threat, according to the abovementioned matrix. Thus, the climate-sensitive health risks presented in the Results below should be considered a synthesis of each country's respective priorities, rather than a true cross-country comparison of risks.

Following the prioritization of these climate change-related health vulnerabilities, relevant adaptation strategies were planned accordingly. Adaptation measures were categorised as follows: legislative and regulatory; public education and communication; surveillance and monitoring; ecosystem intervention; infrastructure development; technological and engineering responses; medical intervention; and research.

Each adaptation measure was prioritised for each PIC according to its local relevance, the current capacity of the health system, the inclusion of vulnerable groups, the manner in which adaptations could be implemented, and the identification of sectors that would be involved in the development and implementation of the adaptation strategies. The country teams – which were typically, but not exclusively, led by the Ministry of Health or its equivalent, in collaboration with other government departments, civil society organisations and major

private sector stakeholders - chose the factors that would be included, and decided upon their relative weighting.

These vulnerabilities and the responses required from the health sector were incorporated into National Climate Change and Health Action Plans (NCCHAPs), or an equivalent thereof. These domestic policy documents are in various stages of finalisation and implementation across the Pacific island countries participating in this regional project.

The vulnerability assessment and adaptation planning process was slightly different for Samoa. An initial workshop on health aspects of vulnerability and adaptation to climate change was conducted in Apia in 2010, as part of a national project entitled “Integrating Climate Change Risks in the Agriculture and Health Sectors in Samoa”. Building on this work, in 2013, a climate change and health adaptation strategy and action plan was developed for Samoa.

The approach was different again for Fiji, which since 2010 has been taking part in a global climate change and health adaptation pilot project, led by WHO with support from the United Nations Development Programme (UNDP) and funding from the Global Environment Facility (GEF - <https://www.thegef.org/>). In Fiji’s *Piloting Climate Change Adaptation to Protect Human Health* project, a small number of priority climate-sensitive diseases were selected as the focus for the vulnerability assessment, research, capacity-building, community education and adaptation elements of the project (McIver et al. 2012).

The process outlined above broadly followed the guidelines laid out by WHO on vulnerability assessment and adaptation planning (Kovats et al. 2003; WHO 2013a). Table 2 compares the WHO theoretical framework with the actual steps implemented in the abovementioned PICs.

In each of the thirteen PICs, efforts were made to include mechanisms for monitoring and evaluation and iterative information management – for example, the incorporation of updated data on climate and climate-sensitive diseases – into each NCCHAP (Ebi 2014).

Results

Table 3 summarizes the climate-sensitive health risks prioritised in each country's vulnerability assessment. These risks are subdivided into three categories: direct, indirect and diffuse effects, in accordance with the international nomenclature (McMichael and Lindgren 2011; McMichael et al. 2013). Examples of direct effects include the traumatic injuries and deaths that occur during hydro-meteorological disasters, and the detrimental physiological consequences of heatwaves. Indirect effects occur through disruption of ecological systems; examples include increased pathogen loads in food and water in hotter and/or more humid conditions, and the altered geographic ranges and biting habits of mosquitoes that spread diseases such as malaria and dengue fever. Diffuse effects relate to societal dysfunction, of which disrupted health services, population displacement and potential conflict over climate-related resources are key examples (Kjellstrom and McMichael 2013).

This was not compiled as – nor was it intended to be – a comprehensive list, describing every conceivable climate change-attributable risk to health; only those risks regarded by the country teams as most important at the present time are included in this summary table. This table is also not intended to serve as a tool for comparison, as while all countries used a similar process of prioritising climate change and health vulnerabilities, each country differed in terms of the number of these hazards they felt it appropriate to address in their respective adaptation plans. Thus, the absence of an entry in a row for a particular country in Table 3 should not be necessarily be interpreted to mean that the country did not perceive that

climate-sensitive health risk to be a problem; rather that this was not among the most immediate priorities for that country at that time.

Table 3 displays some common themes in terms of climate-sensitive health risks across the Pacific. Climate change-attributable impacts on extreme weather events and diseases related to food, water and vectors are prominent concerns throughout the region. Specific diseases such as dengue fever, malaria, diarrhoeal illness, leptospirosis, typhoid fever, respiratory infections, obstructive airways disease and malnutrition are generally considered to be highly climate-sensitive (Woodward et al. 2014). There is thus a clear and relatively urgent need for these and other hazards (such as the health effects of heat and extreme weather events) to be considered in the context of climate change in the Pacific, and anticipated accordingly (Haines et al. 2014).

However, there are some climate-related health risks that are of concern in the Pacific to an extent not documented elsewhere in the world – notably non-communicable diseases (NCDs), disorders of mental/psychosocial health and ciguatera (Mannava et al. 2013; WHO 2013b). The potential for climate change to amplify the drivers of NCD risk in the Pacific is considered in more detail below.

In addition, there are other important aspects of health vulnerability in the region that are unique to, or at least uniquely highly prioritized in, a small number of Pacific island countries. These include high fertility rates and overcrowding in atoll nations such as Kiribati which, combined with limited land area, low elevation and the threat posed by rising seas, may lead to forced relocation – which brings with it a particular suite of health complications (McMichael et al. 2012; Berry et al. 2010).

Women and children are expected to experience a disproportionate burden of climate change and health impacts in the Pacific (Lawler 2011) and elsewhere, particularly in the developing world (Field et al. 2014).

With respect to adaptation, a number of strategies have been proposed and are being implemented across the Pacific region. While some adaptation measures are country-specific (for example, developing legislation around cultural practices such as kava-drinking to protect against water-borne diseases, or experimenting with drought- and salt-resistant taro and cassava crops), the majority may be grouped under broad categories aligned with the abovementioned vulnerabilities. These include:

- Ensuring health and safety considerations are incorporated into adaptation activities across sectors (“Health in All Policies” approach);
- Improving the safety and security of food and water;
- Improving sanitation and hygiene facilities;
- Increased resourcing for health emergency risk management;
- Climate-proofing key health and safety infrastructure;
- Enhanced surveillance targeting climate-sensitive diseases and their risk sources
- Applied environmental epidemiological research focusing on climate-sensitive diseases; and
- New and improved communication pathways between the health sector, meteorology services and other stakeholders, including trialling and evaluating climate-based early warning systems.

Discussion

The climate change and health vulnerability assessment and adaptation planning project in the Pacific is similar in some respects to the corresponding work being carried out in other regions (Brooks and Adger 2003; Confalonieri et al. 2009; Wolf et al. 2014). However, there are some significant differences in terms of the process, findings and implications that distinguish climate change and health issues in PICs from other countries of the world.

In terms of process, the precise methods by which the assessments were performed and adaptations planned varied from country to country. These included highly focused, largely quantitative assessments in the Marshall Islands and FSM, as distinct from a more deliberative, qualitative process employed in Nauru, Solomon Islands and Vanuatu, where a modified environmental health impact assessment approach was employed (Spickett and Katscherian 2014; Spickett et al. 2013). In Kiribati, a mixed-methods, ‘middle way’ approach proved effective in combining a review and analysis of the available data with a pragmatic process of inter-agency collaboration and stakeholder engagement, which has contributed to Kiribati’s NCCHAP being among the first to undergo government ratification and implementation (McIver et al. 2014).

With respect to outcomes, the issue of NCDs, in particular, was of unprecedented prominence in the Pacific in the face of climate change. With PICs already experiencing the highest rates of NCDs in the world (Mannava et al. 2013), the potential for climate change to act as an additional driver of NCD risk is considerable and of significant concern.

While the literature on climate change and NCDs is relatively scant, and has hitherto focused primarily on the implications of heat on individuals with pre-existing NCDs (Friel et al. 2011; Kjellstrom and McMichael 2013; Kovats and Hajat 2008; Shubair et al. 2013), in the Pacific region there is a very real concern that climate change may act as an additional risk factor for

NCDs. It is likely that the Pacific region is – or will be – the first to experience the consequences of the interaction between climate change phenomena and other factors driving the burden of NCDs, such as physical inactivity, food insecurity and poor nutrition. The schema in Figure 3, developed in consultation with the climate change and health team in Nauru - a tiny Pacific island country with one of the highest burdens of NCDs in the world - summarizes these interactions as they are perceived in a number of countries across the region.

It must also be acknowledged that PICs are very likely to be among the first communities to be forced to relocate due to anthropogenic climate change (Campbell 2014). There is some evidence that this forced migration – both internal and external - is already taking place (Birk and Rasmussen 2014; Locke 2009); the physical and psychosocial health consequences of this phenomenon must not be underestimated (Butler et al. 2014; Reuveny 2007).

PICs face substantial challenges in implementing plans for adaptation. They include the scarce resources available to health sectors that are typically already under significant strain. Shortfalls in data, information systems, human resources, technical capacity, infrastructure and finance are the rule, rather than the exception, in the Pacific region.

In light of the stark realities above, many of the adaptation strategies recommended over the course of this climate change and health project were explicitly considered in terms of their overall utility, applicability and feasibility in the context of profoundly under-resourced health systems. Thus, the theoretical requirement for “additionality” mentioned in the international climate change and health literature with respect to adaptation (Füssel 2007) was considered significantly less important for health systems support in the Pacific than pragmatic, realistic measures that would both improve health care and build health systems resilience to climate change. Examples of these include improving water, sanitation and

hygiene systems, and scaling up vector control. Such interventions have clear, broad and long-term benefits, climate change notwithstanding, but they may not be possible for small, developing countries to implement without the avenues for resources and technical support afforded by adaptation.

There may, however, be some modest advantages for PICs in adapting to climate change. Principal among these is the clear consensus about the need for such action – debate about the science and implications of climate change is redundant in these countries which are already experiencing its impacts. In addition, the small size of most PICs, where populations range from around 10 000 in Nauru and Tuvalu to less than a million in Fiji (Table 1), and the close-knit nature of such small, isolated communities, enables a relatively high degree of collaboration on adaptation between sectors, which has the potential for increased agility in decision-making. There is some indication, however faint, that it may yet prove somewhat easier to achieve coherence in climate change and health governance in relatively cohesive Pacific island communities with shared traditional values, than in other countries at varying levels of development but with looser or weaker social capital (Adger 2001; Bowen et al. 2013; Woodward et al. 2000).

There are clear limits to the effectiveness of adaptation, of which some will be tested even if, as is hoped, effective climate change mitigation policy is soon agreed and implemented at global scale. Perhaps the clearest example is that of sea level rise, which threatens the very existence of low-lying island communities, posing an existential threat to the atoll nations of Kiribati, Marshall Islands and Tuvalu (see Table 1).

One of the most promising areas of potential benefit, from both an economic and social perspective, lies in co-benefits – the health gains anticipated from action on climate change mitigation - which are most pertinent in relation to NCDs (Ganten et al. 2010). Well-chosen

disease prevention strategies, such as decreased fossil fuel use; increased active transport (e.g. walking and cycling); and greater consumption of fresh, local foods instead of imported products, have obvious health benefits and will help reduce the pressure on the world's climate.

It is impossible to address vulnerability and adaptation to climate change in the Pacific without pointing out the gross inequities and injustice involved. Pacific island countries have made infinitesimal contributions to the planetary problem of anthropogenic climate change, yet they will be among those who suffer most from its consequences. Industrialised countries have a clear responsibility to both scale-up mitigation efforts in order to arrest climate change, and provide the necessary financial, technical and in-kind support to developing countries to strengthen their coping capacity via adaptation in the meantime.

Finally, recognizing that PICs are among many countries in the world battling climate change as one of a number of significant impediments to social, economic and health development, WHO is in the process of providing detailed guidance, in the form of frameworks, to assist member states in scaling up essential public health packages for health adaptation, and building climate-resilient health systems (Neira 2014).

Conclusion

Pacific island countries are among the most vulnerable societies in the world to the health impacts of a changing climate.

Managing these health risks will require frequent revisions of adaptation plans to take into account post-implementation reviews; new knowledge and understanding of climate change and health processes, pathways and risks; and changes in relevant aspects of Pacific societies such as institutional structures, economic development, technology, and demographics.

This paper, and the corresponding WHO report to be released in late 2015, represent the first comprehensive synthesis of the current state of knowledge of health and climate change in the Pacific islands. This is but the first, important step in a long journey, for which PICs will require substantial and ongoing support.

References

- Adger W. 2001. Social Capital and Climate Change. Tyndall Centre for Climate Change Research, Working Paper 8. University of East Anglia, Norwich, UK.
<http://www.tyndall.ac.uk/sites/default/files/wp8.pdf>
- Berry HL, Bowen K, Kjellstrom T. 2010. Climate change and mental health: a causal pathways framework. *Int. J. Public Health* 55:123–32; doi:10.1007/s00038-009-0112-0.
- Birk T, Rasmussen K. 2014. Migration from atolls as climate change adaptation: Current practices, barriers and options in Solomon Islands. *Nat. Resour. Forum* 38:1–13; doi:10.1111/1477-8947.12038.
- Bowen K, Ebi K, Friel S, McMichael A. 2013. A multi-layered governance framework for incorporating social science insights into adapting to the health impacts of climate change. *Glob. Health Action* 1: 1–6.
- Brooks N, Adger W. 2003. Country level risk measures of climate-related natural disasters and implications for adaptation to climate change. Tyndall Centre for Climate Change Research, Working Paper 26. University of East Anglia, Norwich, UK.
<http://tyndall.ac.uk/sites/default/files/wp26.pdf>
- Brown H, Spickett J, Katscherian D. 2014. A health impact assessment framework for assessing vulnerability and adaptation planning for climate change. *Int. J. Environ. Res. Public Health* 11:12896–914; doi:10.3390/ijerph111212896.
- Butler CD, Bowles DC, McIver L, Page L. 2014. Mental Health, Cognition and the Challenge of Climate Change. In: *Climate Change and Global Health* (Butler C, ed). CABI, Wallingford, UK, 2014; 251–259.
- Butler CD, Harley D. 2010. Primary, secondary and tertiary effects of eco-climatic change: the medical response. *Postgrad. Med. J.* 86:230–234; doi:10.1136/pgmj.2009.082727.
- Campbell JR. 2014. Climate-Change Migration in the Pacific. *Contemp. Pac.* 26:1–28; doi:10.1353/cp.2014.0023.
- Central Intelligence Agency (CIA). CIA World Factbook 2012.
<https://www.cia.gov/library/publications/the-world-factbook/>. Accessed November 2015.
- Confalonieri U, Marinho D, Rodriguez R. 2009. Public health vulnerability to climate change in Brazil. *Clim. Res.* 40:175–186; doi:10.3354/cr00808.

Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R, et al. 2009. Managing the health effects of climate change: Lancet and University College London Institute for Global Health Commission. *Lancet* 373:1693–733; doi:10.1016/S0140-6736(09)60935-1.

Ebi KL. 2014. National and Global Monitoring and Surveillance Systems for the Health Risks of Global Change. 649–655; doi:10.1007/978-94-007-5784-4.

Field CB, Barros V, Dokken DJ, et al. Climate change 2014: impacts, adaptation, and vulnerability. Volume I: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge and New York: Cambridge University Press, 2014. http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-TS_FINAL.pdf

Friel S, Bowen K, Campbell-Lendrum D, Frumkin H, McMichael a J, Rasanathan K. 2011. Climate change, noncommunicable diseases, and development: the relationships and common policy opportunities. *Annu. Rev. Public Health* 32:133–47; doi:10.1146/annurev-publhealth-071910-140612.

Füssel HM. 2007. Adaptation planning for climate change: Concepts, assessment approaches, and key lessons. *Sustain. Sci.* 2:265–275; doi:10.1007/s11625-007-0032-y.

Galea G, Powis B, Tamplin SA. 2000. Healthy Islands in the Western Pacific — international settings development. *Health Promot. Int.* 15: 169–178.

Ganten D, Haines A, Souhami R. 2010. Health co-benefits of policies to tackle climate change. *Lancet* 376:1802–4; doi:10.1016/S0140-6736(10)62139-3.

Haines A, Ebi KL, Smith KR, Woodward A. 2014. Health risks of climate change: act now or pay later. *Lancet* 384:1073–1075; doi:10.1016/S0140-6736(14)61659-7.

Hanna E, McIver L. 2014. Small Island States – Canaries in the Coal Mine of Climate Change and Health. In: *Climate Change and Global Health* (Butler C, ed). CABI, Wallingford, UK, 2014; 181–192.

Kjellstrom T, McMichael AJ. 2013. Climate change threats to population health and well-being: the imperative of protective solutions that will last. *Glob. Health Action* 6: 1–9.

Kovats R, Ebi K, Menne B. Methods of assessing human health vulnerability and public health adaptation to climate change. World Health Organization, Copenhagen, Denmark, 2003. http://www.euro.who.int/__data/assets/pdf_file/0009/91098/E81923.pdf

Kovats RS, Hajat S. 2008. Heat stress and public health: a critical review. *Annu. Rev. Public Health* 29:41–55; doi:10.1146/annurev.publhealth.29.020907.090843.

Lawler. 2011. Children's vulnerability to climate change and disaster impacts in East Asia and the Pacific. UNICEF East Asia and Pacific Regional Office, Bangkok, Thailand.

Locke JT. 2009. Climate change-induced migration in the Pacific Region: sudden crisis and long-term developments. *Geogr. J.* 175:171–180; doi:10.1111/j.1475-4959.2008.00317.x.

Mannava P, Abdullah A, James C, Dodd R, Annear PL. 2013. Health Systems and Noncommunicable Diseases in the Asia-Pacific Region: A Review of the Published Literature. *Asia. Pac. J. Public Health*; doi:10.1177/1010539513500336.

McIver L, Kim R, Woodward A, Hales S, Spickett J, Katscherian D, Hashizume M, Kim H, Honda Y, Naicker J, Bambrick H, Iddings S. 2015a. Human health and climate change in Pacific island countries. WHO Western Pacific Regional Office, Manila, Philippines (in press)

McIver L, Hashizume M, Kim H, Honda Y, Pretrick M, Iddings S, et al. 2015b. Assessment of climate-sensitive infectious diseases in the Federated States of Micronesia. *Trop. Med. Health* 43:29–40; doi:10.2149/tmh.2014-17.

McIver L, Naicker J, Hales S, Singh S, Dawainavesi A. 2012. Climate change and health in Fiji: environmental epidemiology of infectious diseases and potential for climate-based early warning systems. *Fiji J. Public Heal.* 1:7–13; doi:10.1038/gim.2013.195.

McIver L, Woodward A, Davies S, Tibwe T, Iddings S. 2014. Assessment of the Health Impacts of Climate Change in Kiribati. *Int. J. Environ. Res. Public Health* 11:5224–5240; doi:10.3390/ijerph110505224.

McMichael AJ. 2013. Globalization, Climate Change, and Human Health. *N. Engl. J. Med.* 368:1335–1343; doi:10.1056/NEJMra1109341.

McMichael AJ, Lindgren E. 2011. Climate change: present and future risks to health, and necessary responses. *J. Intern. Med.* 270:401–13; doi:10.1111/j.1365-2796.2011.02415.x.

McMichael C, Barnett J, McMichael AJ. 2012. An Ill Wind? Climate Change, Migration, and Health. *Environ. Health Perspect.* 646–654.

Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 2007. Cambridge: Cambridge University Press, 2007.
https://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch8.html

Neira M. 2014. The 2014 WHO conference on health and climate. *Bull. World Health Organ.* 92: 546.

Reuveny R. 2007. Climate change-induced migration and violent conflict. *Polit. Geogr.* 26:656–673; doi:10.1016/j.polgeo.2007.05.001.

Shubair M, Haider M, Bassa M. 2013. Climate Change and Type 2 Diabetes. *J. Endocrinol. Diabetes Mellit.* 1: 22–26.

Spickett JT, Katscherian D. 2014. Health Impacts of Climate Change in the Solomon Islands: An Assessment and Adaptation Action Plan. *Glob. J. Health Sci.* 6:261–273; doi:10.5539/gjhs.v6n5p261.

Spickett JT, Katscherian D, McIver L. 2013. Health Impacts of Climate Change in Vanuatu: An Assessment and Adaptation Action Plan. *Glob. J. Health Sci.* 5:42–53; doi:10.5539/gjhs.v5n3p42.

Stephenson J, Crane SF, Levy C, Maslin M. 2013. Population, development, and climate change: links and effects on human health. *Lancet* 382:1665–1673; doi:10.1016/S0140-6736(13)61460-9.

United Nations Office of the High Representative for the Least Developed Countries, Landlocked Countries and Small Island Developing States (UNOHRLLS). <http://unohrlls.org/>. Accessed November 2015.

Wolf T, Martinez GS, Cheong H-K, Williams E, Menne B. 2014. Protecting Health from Climate Change in the WHO European Region. *Int. J. Environ. Res. Public Health* 11:6265–80; doi:10.3390/ijerph110606265.

Woodward A, Hales S, Litidamu N, Phillips D, Martin J. 2000. Protecting human health in a changing world: the role of social and economic development. *Bull. World Health Organ.* 78: 1148–1155.

Woodward A, Smith K, Campbell-Lendrum D, Chadee D, Honda Y, Liu Q, et al. 2014. Climate change and health: on the latest IPCC report. *Lancet* 6736: 1–5.

World Health Organization. 2007. Regional Framework for Action to Protect Human Health from Effects of Climate Change in the Asia-Pacific Region. 1–4. Manila, Philippines. https://unfccc.int/files/adaptation/sbsta_agenda_item_adaptation/application/pdf/who_searo_regional_network.pdf

World Health Organization. 2009. Madang Commitment. Joint publication by WHO and the Secretariat of the Pacific Community. Geneva, Switzerland. http://www.wpro.who.int/southpacific/pic_meeting/reports/madang_commitment_2009.pdf

World Health Organization. 2013a. WHO guidance to protect health from climate change through health adaptation planning. Villalobos-Prats E and Ebi, K, eds. Geneva,

Switzerland. <http://www.who.int/globalchange/publications/guidance-health-adaptation-planning/en/>

World Health Organization. 2013b. WHO Multi-Country Cooperation Strategy for the Pacific (2013-2017). Manila, Philippines.
http://www.wpro.who.int/southpacific/who_pacific_mccs.pdf

Table 1. Characteristics of Pacific island countries

Pacific island country	Geography		Demography		Economy	
	Land area (km ²) ^a	Max elevation (m) ^b	Population ^b	Population density (per km ²)	Per capita GDP ^{b,c}	Main industries # (% GDP) ^b
Cook Islands	240	652	15 000	42	9100	T
Federated States of Micronesia	700	791	112 000	158	2200	A, F
Fiji	18 000	1324	868 000	47	4600	T, A
Kiribati	800	3, 81 ^d	101 000	135	6200	A, F, R
Marshall Islands	200	10	64 000	342	2500	Aid (US)
Nauru	20	71	10 000	480	5000	M
Niue	260	68	1000	5	8400	Aid (NZ)
Palau	500	242	21 000	39	10 000	T A, F
Samoa	2900	1857	184 000	63	6000	R, T, A, F
Solomon Islands	28 000	2335	552 000	18	3300	A, F, forestry
Tonga	750	1033	105 000	139	7500	A, F
Tuvalu	300	5	10 000	476	3400	R, trusts, A
Vanuatu	12 000	1877	246 000	20	2700	A, F, T

Abbreviations: A= Agriculture, F= Fishing, M= Mining, NZ=New Zealand, R=Remittances, T= Tourism, US=United States

All data are for 2011 unless otherwise stated

^aUN Office of the High Representative for the Least Developed Countries, Landlocked Countries and Small Island Developing States (UN-OHRLLS: www.unohrlls.org)

^bCIA World Factbook 2012

^cPer capita Gross Domestic Product based on purchasing power parity. Estimates are for 2011 except for the Marshall Islands (2008), Nauru (2005), Palau (2009), Tuvalu (2010) and Vanuatu (2009)

^dElevations for South Tarawa (the capital atoll of Kiribati) and Banaba (an outlying atoll) respectively

Table 2. Steps involved in vulnerability assessment and adaptation planning process in PICs and comparison with WHO framework (the latter adapted from Kovats et al. 2003)

WHO framework for vulnerability assessment and adaptation planning	Vulnerability assessment and adaptation planning process implemented in PICs
Determine scope of assessment	<ul style="list-style-type: none"> • Project designed and resourced • Eleven PICs divided into three regions along roughly geographic and cultural lines • Expert technical guidance provided to each group • Inception meetings held and workplans made for each country
Describe current distribution and burden of climate-sensitive diseases	<ul style="list-style-type: none"> • Available information and data on climate and climate-sensitive diseases reviewed and described in each country • Environmental epidemiological analysis undertaken where possible
Identify and describe current strategies, policies and measures that reduce the burden of climate-sensitive diseases	<ul style="list-style-type: none"> • Health sector and other relevant policies (e.g. climate change policies, strategic development plans) reviewed and linked with health adaptation planning
Review the health implications of the potential impact of climate variability and change on other sectors	<ul style="list-style-type: none"> • Wide stakeholder, cross-sectoral engagement ensured in health adaptation planning
Estimate the future potential health impact using scenarios of future climate change, population growth and other factors and describe the uncertainty	<ul style="list-style-type: none"> • Some modelling of future climate change-attributable burden of disease attempted; limited by lack of down-scaled climate projections and sufficient quantity and quality of data on climate-sensitive diseases
Synthesize the results and draft a scientific assessment report	<ul style="list-style-type: none"> • NCCHAPs – or equivalent – prepared for each of the eleven PICs
Identify additional adaptation policies and measures to reduce potential negative health effects, including procedures for evaluation after implementation	<ul style="list-style-type: none"> • Adaptation strategies prioritised • Highest priority adaptations commenced in some PICs (see Table 3) • Guidance provided to countries on methods for iterative information management, monitoring and evaluation

Table 3. Highest priority climate-sensitive health risks in individual Pacific island countries (with each country’s highest priorities indicated by “X”)

Climate-sensitive health risk	Country												
	Cook Islands	FSM	Fiji	Kiribati	Marshall Islands	Nauru	Niue	Palau	Samoa	Solomon Islands	Tonga	Tuvalu	Vanuatu
Direct effects													
Health impacts of extreme weather events ^a	x	x			x	x	x	x	x	x	x	x	x
Heat-related illness ^b	x					x	x			x			x
Indirect effects													
Water security & safety (including water-borne diseases) ^c	x	x	x	x	x	x	x	x	x	x	x	x	x
Food security & safety (including malnutrition & food-borne diseases) ^d	x	x	x	x	x	x	x		x	x	x	x	x
Vector-borne diseases ^e	x	x	x	x	x	x	x	x	x	x	x	x	x
Zoonoses ^f		x	x					x					
Respiratory illness ^g	x	x			x	x	x	x		x		x	x

Disorders of the eyes, ears, skin and other body systems ^h			x		x		x			x		x	x
Diffuse effects													
Disorders of mental/psycho-social health ⁱ		x	x		x	x		x		x		x	x
Non-communicable diseases (NCDs) ^j		x	x		x		x	x	x	x	x	x	x
Health system deficiencies ^k			x	x									
Population pressures ^l				x									

NB. A number of climate-sensitive health risks may be considered to cut across categories – for example, there may be direct mental health consequences of extreme weather events; NCDs may be affected indirectly through disruption of food supplies, or more diffusely through socio-political strategies related to climate change, industry and trade; health systems problems may be directly affected by extreme weather events as well as via the broader impact of climate change on development

^aThis was typically taken to mean traumatic injuries and deaths, but may also be understood to include the psychosocial impacts of extreme events

^bIncluding occupational exposure to hotter working conditions

^cThis category encompasses water-borne infections causing diarrhoeal illness, as well as typhoid fever, and also includes problems such as sea-level rise-induced salination of potable water supplies

^dIncluding food insecurity, food-borne diseases causing diarrhoeal illness, and ciguatera (“fish poisoning”)

^eIncluding, but not limited to, dengue fever and malaria; noting that these two diseases occur in some, but not all, PICs (of those countries listed, malaria is currently limited to Solomon Islands and Vanuatu)

^fThe primary zoonosis of concern in most PICs is leptospirosis

^gIncluding infections, obstructive airways disease (e.g. asthma) and the pulmonary effects of heat and air pollution

^hThis category includes a range of health problems, from skin infections and cataracts to sexually transmitted infections that were of concern in various PICs in the context of climate change

ⁱIncludes the unspecified detrimental effects of social disruption – e.g. loss of life, land or livelihoods - due to climate change-related phenomena; this category may include, *inter alia*, depression, anxiety and post-traumatic stress disorder

^jNCDs in this context refers primarily to circulatory diseases (e.g. cardiovascular disease, cerebrovascular diseases, hypertension etc) as well as diabetes; in some PICs this was also taken to include cancers and mental health disorders

^kIncluding compromised access to health services, damage to health infrastructure and additional strains on scarce resources (e.g. for climate-sensitive disease surveillance)

^lIncludes the possibility of climate change-induced resettlement, and the effect of climate change-induced sea-level rise in exacerbating overcrowding

Figure legends

Figure 1. Climate change and health impact pathways relevant to Pacific island countries

Figure 2. Countries involved in WHO-supported climate change and health project in the Pacific (2010-2013) (Adapted from source: CartoGIS, College of Asia and Pacific, The Australian National University - <http://asiapacific.anu.edu.au/mapsonline/base-maps/pacific-eez-zones>)

Figure 3. Conceptual model summarizing the pathways between climate change and NCDs (broken arrows represent hypothetical links)

Figure 1.

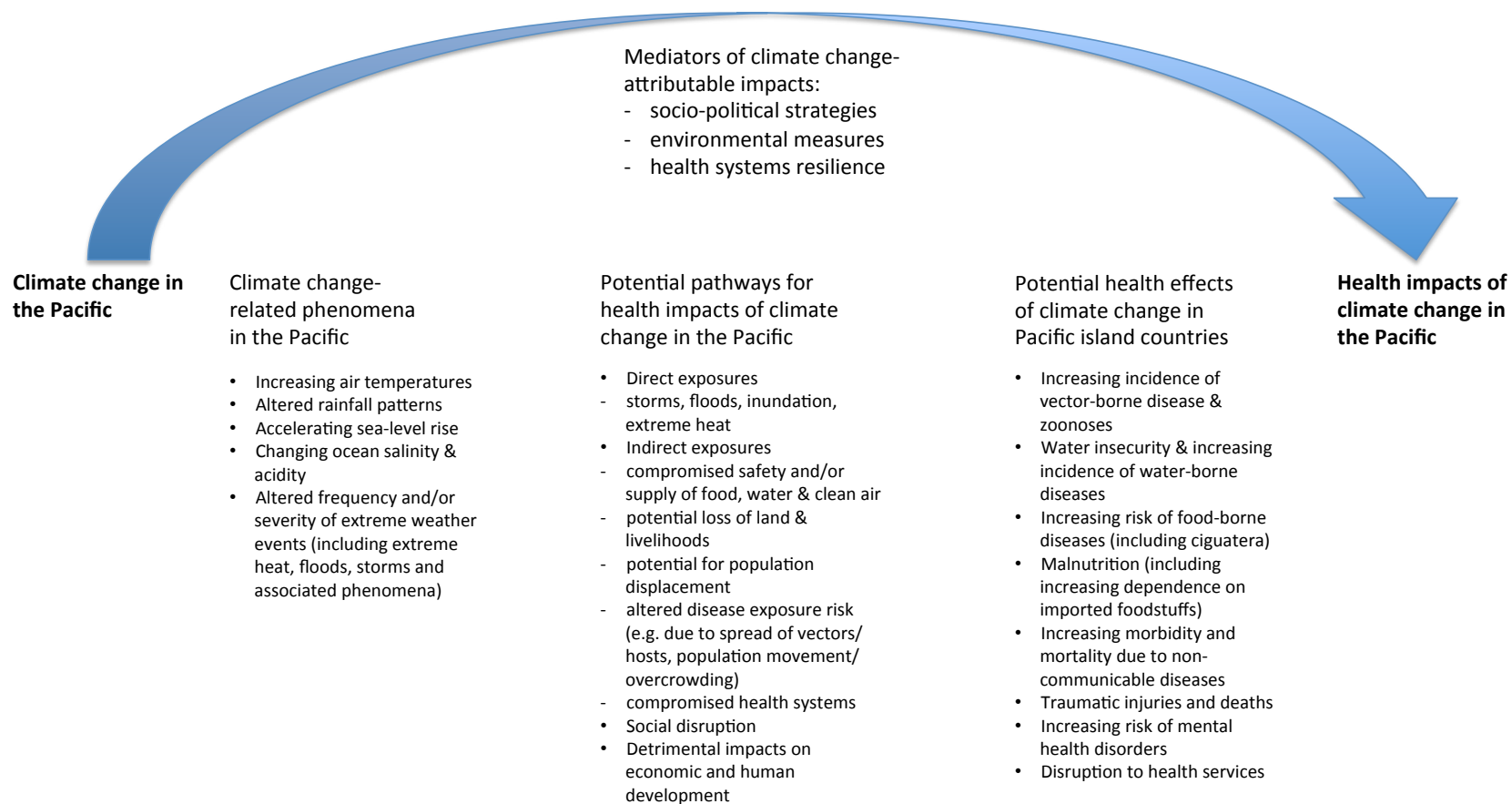
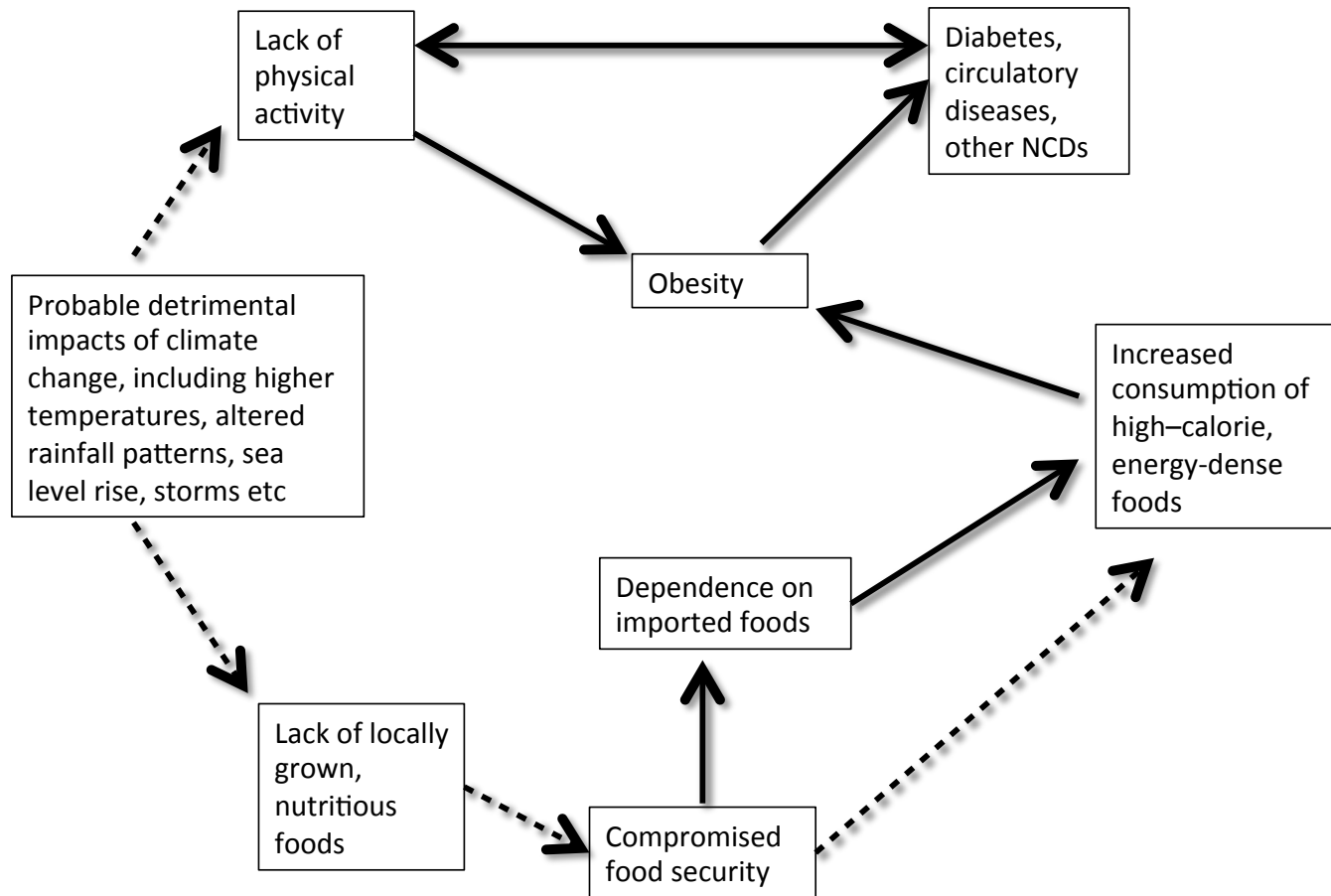


Figure 2.



Figure 3.



Chapter Five

Paper 2: Assessment of climate-sensitive infectious diseases in the Federated States of Micronesia

Prelude

This chapter is the first of the country-specific publications, which together provide examples of the main techniques employed in the climate change and health vulnerability assessments and adaptation planning processes in the Pacific, and the key findings and implications of this work for each country.

In this paper, which focuses on the Federated States of Micronesia (FSM), a predominantly quantitative methodology was used to explore the climate-sensitivity of the communicable diseases considered to represent the greatest risks for climate change and health in that country (particularly diarrhoeal diseases).

The use of historical climate and disease data, analysed via time series and Poisson regression techniques in FSM and, to a lesser extent, in Marshall Islands and Palau, contrasted with more qualitative - yet still highly systematic - approaches to the vulnerability assessment process in other Pacific island countries, examples of which follow in subsequent chapters.

The candidate's estimated proportional contributions to this paper were as follows:

Research design:	60%
Analysis and interpretation:	60%
Authorship of paper:	80%

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Original Paper

Assessment of Climate-sensitive Infectious Diseases in the Federated States of Micronesia

Lachlan McIver^{1*†}, Masahiro Hashizume², Ho Kim³, Yasushi Honda⁴, Moses Pretrick⁵, Steven Iddings^{6†}
and Boris Pavlin⁷

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Abstract: Background: The health impacts of climate change are an issue of growing concern in the Pacific region. Prior to 2010, no formal, structured, evidence-based approach had been used to identify the most significant health risks posed by climate change in Pacific island countries. During 2010 and 2011, the World Health Organization supported the Federated States of Micronesia (FSM) in performing a climate change and health vulnerability and adaptation assessment. This paper summarizes the priority climate-sensitive health risks in FSM, with a focus on diarrheal disease, its link with climatic variables and the implications of climate change.

Methods: The vulnerability and adaptation assessment process included a review of the literature, extensive stakeholder consultations, ranking of climate-sensitive health risks, and analysis of the available long-term data on climate and climate-sensitive infectious diseases in FSM, which involved examination of health information data from the four state hospitals in FSM between 2000 and 2010; along with each state's rainfall, temperature and El Niño-Southern Oscillation data. Generalized linear Poisson regression models were used to demonstrate associations between monthly climate variables and cases of climate-sensitive diseases at differing temporal lags.

Results: Infectious diseases were among the highest priority climate-sensitive health risks identified in FSM, particularly diarrheal diseases, vector-borne diseases and leptospirosis. Correlation with climate data demonstrated significant associations between monthly maximum temperature and monthly outpatient cases of diarrheal disease in Pohnpei and Kosrae at a lag of one month and 0 to 3 months, respectively; no such associations were observed in Chuuk or Yap. Significant correlations between disease incidence and El Niño-Southern Oscillation cycles were demonstrated in Kosrae state.

Conclusions: Analysis of the available data demonstrated significant associations between climate variables and climate-sensitive infectious diseases. This information should prove useful in implementing health system and community adaptation strategies to avoid the most serious impacts of climate change on health in FSM.

Key words: infectious diseases, climate, Federated States of Micronesia

INTRODUCTION

Pacific island countries (PICs) are among the most vulnerable in the world to the effects of climate change, including the likely detrimental impacts on human health [1, 2]. These impacts are significant, measurable and far-reaching: it is estimated that over the last decade, between 100,000 and 200,000 deaths annually worldwide were attributable to the effects of climate change [3]. In the

Pacific region, growing concern about climate change and health led to the formulation of the Regional Framework for Action to Protect Human Health from Effects of Climate Change in the Asia-Pacific Region by the World Health Organization (WHO) in 2008 [4] and prompted the Pacific island Health Ministers to prioritize action on climate change and health at their biennial meeting in 2009 [5]. These regional mandates provided the impetus for an ambitious program of work, led by the WHO South Pacific

¹ National Centre for Epidemiology and Population Health, Australian National University, Canberra, Australia

² Institute of Tropical Medicine, Nagasaki University, 1-12-4 Sakamoto, Nagasaki 852-8523 Japan

³ Graduate School of Public Health, Seoul National University, Building 221, 1 Gwanak-ro, Gwanak-gu, Seoul, Korea 151-742

⁴ University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-0006, Japan

⁵ Department of Health and Social Affairs, P.O. Box PS 70 Palikir, Pohnpei 96941, Federated States of Micronesia

⁶ World Health Organization, Sankat Chak Tomouk, Khan Daun Penh, Phnom Penh, Cambodia

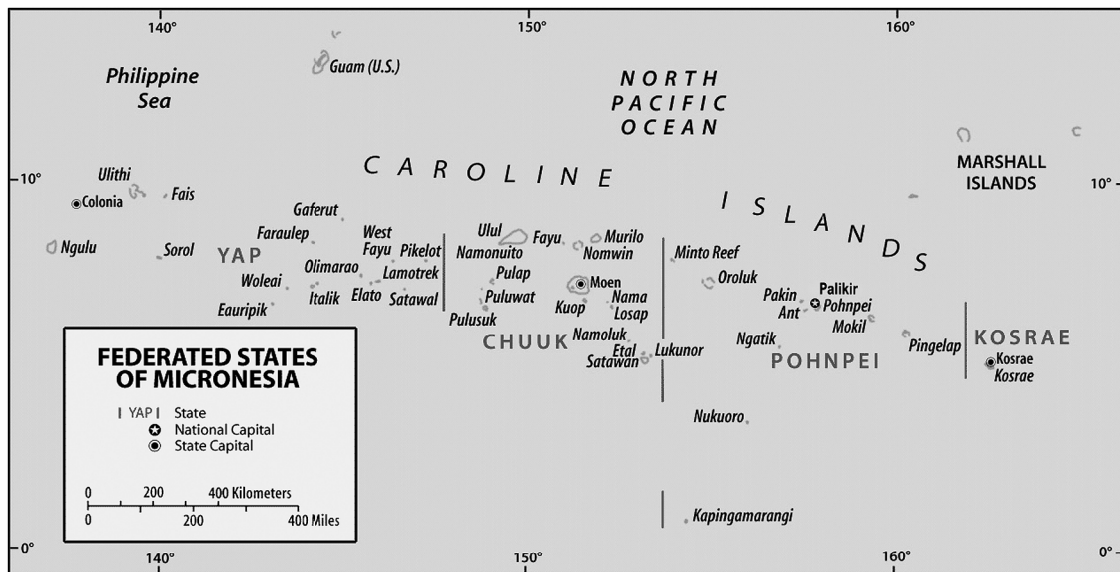
⁷ World Health Organization, 4th Floor, Aopi Centre, Waigani Drive, Port Moresby, Papua New Guinea

*Corresponding author:

Tel & Fax: +613 9421 6754

E-mail: lachlan.mciver@gmail.com

†Previously of WHO Division of Pacific Technical Support, Suva, Fiji



Map 1. Federated States of Micronesia (source: <http://www.fsmgov.org/info/maplg.gif>)

office, with support from the WHO Western Pacific Regional Office and funding from the governments of the Republic of Korea and Japan, to assess the vulnerability of PICs to the impact of climate change on health and plan appropriate adaptation strategies to minimize these risks.

The Federated States of Micronesia (FSM) was one of eleven countries involved in this WHO-supported climate change and health project in the Pacific. FSM is a small island developing state in the northern Pacific, comprised of four states – Yap, Chuuk, Pohnpei and Kosrae (see Map 1).

A summary of key population and health indicators for FSM is provided in Table 1.

The key climate change phenomena expected to occur in FSM include [6]: accelerating sea-level rise and ocean acidification; increasing air and sea-surface temperatures; more very hot days; altered rainfall patterns (with more extreme rainfall events and decreased drought frequency); and possibly more severe typhoons.

In FSM, prior to the commencement of the WHO project, climate change and health considerations had been included in several key high-level national policy frameworks, including the Nationwide Climate Change Policy (2009), the Second National Communication to the United Nations Framework Convention on Climate Change (UNFCCC), and the National Strategic Development Plan for 2003–2023. This previous work noted that climate variability and change, including sea-level rise, are important determinants of health and are of growing concern in FSM (as is the case in all Pacific Island countries), with the impacts expected to be mostly adverse. However, these pre-

ceding efforts toward health vulnerability assessments lacked formal health sector and expert technical input.

Thus, the purpose of this project was to assess more formally the key climate-sensitive health risks for FSM, based on a review of the relevant literature, in-country consultations and analysis of available climate and health data, and to provide an evidence-based framework for climate change and health adaptation, as the health sector's contribution towards national adaptation planning (or HNAP).

This paper summarizes the methodology and results of this climate change and health vulnerability assessment for FSM, with a focus on climate-sensitive infectious diseases, which were ranked as the highest priority climate-sensitive health risks in FSM as a result of this assessment process. The paper also provides an insight into the scientific basis for implementation of adaptation strategies to reduce or avoid the most serious impacts of climate change on the burden of these diseases in FSM.

METHODS

The process for assessing FSM's vulnerabilities and planning adaptation strategies related to the health impacts of climate change broadly followed the guidelines set out by WHO and others [7–11]. These steps are summarized in Box 1.

Table 1. Key population and health indicators for FSM

Indicator	Total
Land area ^a (square kilometres)	704.6 - Chuuk: 127 - Kosrae: 110 - Pohnpei: 345 - Yap: 118
Population – total and distribution ^b	102 624 - Chuuk: 49% - Kosrae: 8% - Pohnpei: 32% - Yap: 11%
Key health indicators ^b - life expectancy (at birth) - infant mortality rate - under 5 mortality rate	69 13.5/1000 live births 39/1000 live births
Leading causes of morbidity (inpatient) ^b	Hypertension Diarrhea/gastroenteritis Diabetes mellitus Skin disorders Urinary tract infection
Leading causes of mortality ^b	Myocardial infarction Diabetes mellitus Chronic obstructive pulmonary disease Cerebrovascular accident
Top three communicable disease categories (burden of disease, by incidence) ^b	Acute upper respiratory infections Influenza-like illness Diarrhea/gastroenteritis
Top three non-communicable diseases (burden of disease, by prevalence) ^b	Hypertension Diabetes mellitus Cardiovascular disease

Sources: a) FSM Government website (<http://www.fsmsgov.org/info/geog.html>)

b) WHO Country Health Information Profile for FSM (2011) (http://www.wpro.who.int/countries/fsm/17MICtab2011_finaldraft.pdf?ua=1)

Box 1. Steps in assessing vulnerability and adaptation (Source: Kovats *et al.*, 2003 [11]).

1. Determine the scope of the assessment
2. Describe the current distribution and burden of climate-sensitive diseases
3. Identify and describe current strategies, policies and measures that reduce the burden of climate-sensitive diseases
4. Review the health implications of the potential impact of climate variability and change on other sectors
5. Estimate the future potential health impact using scenarios of future climate change, population growth and other factors and describe the uncertainty
6. Synthesise the results and draft a scientific assessment report
7. Identify additional adaptation policies and measures to reduce potential negative health effects, including procedures for evaluation after implementation

In FSM, this process incorporated both qualitative and quantitative elements. These included stakeholder consultations, community surveys, expert consensus and analysis of the available climate and health data to describe, in some detail, the relationships between climate variables and climate-sensitive diseases in each country.

The climate change and health vulnerability and adaptation assessment process in FSM commenced in 2010, with a project—led by the Department of Health and Social Affairs and supported by WHO—aimed at improving understanding of the relationship between climate and disease in the four States of FSM and compiling a National Climate Change and Health Action Plan (NCCHAP). This project involved a WHO team assisting the Department of Health and Social Affairs over three distinct phases of work between 2010 and 2011, with the participation of multiple in-country partners including, *inter alia*, the Office for Environment and Emergency Management

(OEEM), the Environmental Protection Agency (EPA) and the Weather Service Office (WSO).

The first phase of the project was a regional plenary meeting, conducted in Pohnpei in early 2010, which included representatives from the neighbouring countries of Palau and the Republic of the Marshall Islands who were conducting similar WHO-supported national vulnerability and adaptation assessment projects.

In the first and second phases of the project, a review of health sector reports and data, combined with extensive consultation with stakeholders in FSM and the guidance of the WHO team of experts, revealed a list of priority climate-sensitive health risks of concern in the country. These climate-sensitive health risks were then ranked according to a “likelihood versus impact” matrix, which has proved useful in environmental health impact assessments elsewhere, including in the context of climate change and health [12, 13]—see Table 2 below.

The actors involved in the participatory action process of consensus-building regarding the priority climate-sensitive health risks in FSM are listed in Table 3.

The process of prioritization of climate-sensitive health risks of concern in FSM placed an emphasis on infectious diseases, which were thus the focus of the quantitative analysis that followed.

The climate-sensitive disease data from the four State hospital records (inpatient and outpatient) between 2003 and 2010 were collected from the Health Information De-

partment. Hospital records include sex, age and diagnosis coded by the International Classification of Diseases, version 10 (ICD-10). These records represent the most complete health datasets available on a routinely collected basis in FSM, apart from a complementary, Pacific-wide syndromic surveillance system (specific to for four categories of communicable disease) overseen by WHO. Thus it is assumed that these represent close to all of the reported cases; the proportion of unreported cases is unknown.

Weather data were collected from the WSO. The individual patient data were collated into daily all-cause and cause-specific counts and combined with daily weather data, with this study focusing on the aforementioned priority climate-sensitive infectious diseases.

Time series distribution of monthly average of the daily number of inpatients and outpatients in each state were plotted along with weather data. Monthly averages of daily maximum temperatures were computed; these and total monthly rainfall were used for the subsequent analyses. Time series analysis of the three climate-sensitive infectious diseases deemed to be the highest risk were then performed [dengue fever (ICD-10: A90-A91), diarrheal illness (ICD-10: A00-A09) and leptospirosis (ICD-10: A27)].

The association with the El Niño-Southern Oscillation (ENSO), a source of inter-annual climate variability, was also examined for each disease category. The strength of the ENSO was measured by sea-surface temperature

Table 2. Matrix used to assess climate-sensitive health risks in FSM, in terms of their likelihood and impact

Likelihood	Impact (Considering consequence and coping capacity)				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	Medium	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Possible	Low	Medium	Medium	High	High
Unlikely	Low	Low	Medium	Medium	Medium
Rare	Low	Low	Low	Low	Medium

Table 3. Actors involved in participatory decision-making process in FSM

Actors	FSM
Coordination	Office for the Environment and Emergency Management Department of Health and Social Affairs WHO
Participation	Environmental Protection Agency Weather Service Office Department of Resources and Development Department of Agriculture State health and environment services Island Food Community*

* Non-governmental organization (NGO)

anomalies in the Niño 3 region (NINO3) in the Pacific Ocean, which were derived from NOAA Climate Prediction Center data (<http://www.cpc.ncep.noaa.gov>).

Generalized linear Poisson regression models allowing for over-dispersion were used to examine the relationship between weather variables (temperature and rainfall) and NINO3 variability and the number of cause-specific patient presentations at different monthly lags (0, 1, 2 and 3 months), with a focus on outpatients. This analytical technique was selected based on historical and scientific precedents for its use in comparable studies [14]. To identify the broad shape of any association, we fitted natural cubic splines (3df) to the weather variables and NINO3. The temperature, rainfall and NINO3 terms were separately incorporated into the model. As there was no clear seasonal trends observed in disease incidence, seasonality was not controlled in the model. Overall association for each disease-weather pattern was tested using Wald test. Any missing data was treated as missing; no interpolation has been conducted to fill the missing values. All statistical analyses were carried out using Stata 10.0 (Stata Corporation, College Station, Texas).

The results of the vulnerability assessment were then used to compile a hierarchy of adaptation strategies for the health sector, and all of this information was collated into the FSM National Climate Change and Health Action Plan (NCCCHAP), which was presented at the inaugural FSM Climate Change and Health Symposium in Pohnpei in December 2011.

The key findings and recommendations from the FSM NCCCHAP and the companion documents for the other ten PICs included in the WHO-led project have subsequently

been synthesized into a forthcoming WHO report on climate change and health in the Pacific region, which will be launched in late 2014.

RESULTS

Review of the relevant data and extensive consultation with stakeholders, primarily from government departments, in FSM between 2010 and 2011, in combination with a review of the literature (the specific methodology and results of which are not shown here) and the expert opinions of the WHO consultant team, yielded the following table of climate-sensitive health vulnerabilities (Table 4), ranked according to their risk (in terms of likelihood versus impact—see Table 2 above).

While allowing for the fact that the list in Table 4 is based on a combination of health information review, consultation and expert consensus, this nevertheless indicates that the predominant climate-sensitive health risks of concern in FSM are likely to be infective in nature. The process of quantitative analysis therefore focused on three categories of climate-sensitive infectious diseases: diarrheal illness, vector-borne diseases and leptospirosis. This analysis was attempted despite the paucity of relevant health data, as this was the express mandate of the climate change and health vulnerability assessment project, as well as being the preferred methodological approach of WHO and the project partners in FSM.

Time series of monthly average of daily dengue, diarrhea and leptospirosis inpatients showed no obvious trend or seasonality (the results for Pohnpei state are shown in Fig. 1).

Table 4. List of climate change and health vulnerabilities in FSM

Climate-sensitive disease	Risk (likelihood versus impact)
Diarrheal diseases (water- and food-borne)	High
Vector-borne diseases (principally arboviruses such as dengue fever)*	High
Zoonoses (primarily leptospirosis)	High
Malnutrition	High
Non-communicable diseases	Medium
Mental health	Medium
Respiratory diseases	Medium
Skin disease	Medium
Poverty and socio-economic disadvantage	Medium
Traumatic injuries and deaths	Low
Ciguatera**	Low

* Lymphatic filariasis and malaria were also considered under the heading of vector-borne diseases, but were deemed to represent significantly lower risks than arboviruses in the context of climate change in FSM (see below).

** Ciguatera is a toxidrome caused by a dinoflagellate organism which bio-accumulates in the marine food chain. Humans typically contract ciguatera through consumption of contaminated reef fish.

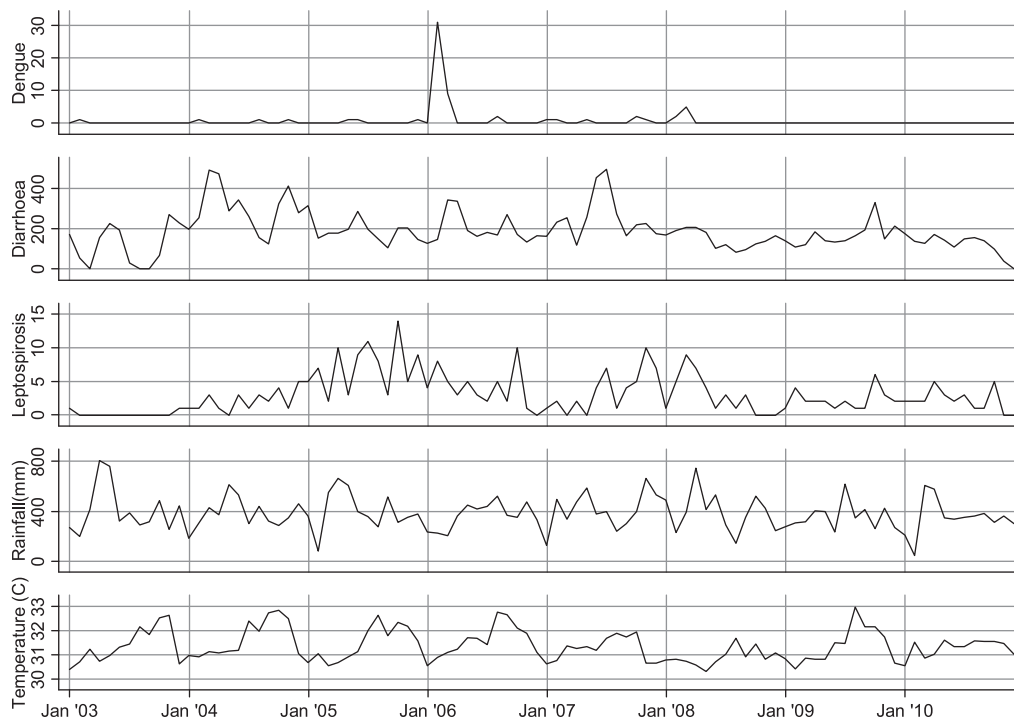


Fig. 1. Number of dengue, diarrhea and leptospirosis outpatients per month and weather variables (total rainfall and average temperature) in Pohnpei

As can be seen from Figure 1, there were substantial gaps in the data for all three disease categories, as was the case for the other three states. This apparently reflects intermittent lapses in health information capacity within the Department of Health and Social Affairs in each of the states over the period.

There were also generally low rates of dengue fever and leptospirosis in all four states, with less than 0.5 cases occurring on average per day (i.e. approximately <15 cases per month) in each state. It should be noted that, while diarrheal disease and leptospirosis are considered endemic in FSM, dengue fever typically occurs in infrequent but severe epidemics [15, 16]. Given these very small numerators, along with the infeasibility of aggregating all the cases for correlation with climate variables given the significantly asynchronous meteorological patterns between states, no further environmental epidemiological analysis of dengue fever and leptospirosis was undertaken in this study.

There may be an apparent threshold effect for increased cases of diarrheal illness in Pohnpei at a lag of one month following monthly maximum temperatures of $\geq 32\text{--}33^\circ\text{C}$ (see Fig. 2b).

The corresponding analysis for Kosrae state showed a similar effect of high temperature ($> 32^\circ\text{C}$) at lags of 0 and 1 month, although the relationship was weaker than that

observed for Pohnpei. In addition, a negative relationship between temperature and diarrhea cases was observed in Kosrae below 31°C (see Fig. 3). It is possible that different pathogens contribute to the two curves or slopes of this apparently U-shaped relationship.

The analysis was repeated for rainfall, but no significant relationship was found in any of the four states (results not shown).

Diarrheal illness was also correlated with NINO3 at different monthly lags, with an apparently statistically significant, roughly U-shaped relationship demonstrated for Kosrae (Fig. 4), but no statistically significant results were found for the other three states.

DISCUSSION

This study revealed that the principal health risks posed by climate change in FSM include a number of climate-sensitive infectious diseases. Of these, diarrheal disease has been shown to be associated with climatic factors such as temperature and the ENSO index in at least two of the states of FSM.

The following discussion therefore focuses on climate-sensitive infectious diseases, particularly diarrheal disease, given the high level of priority given to these issues in the climate change and health vulnerability assess-

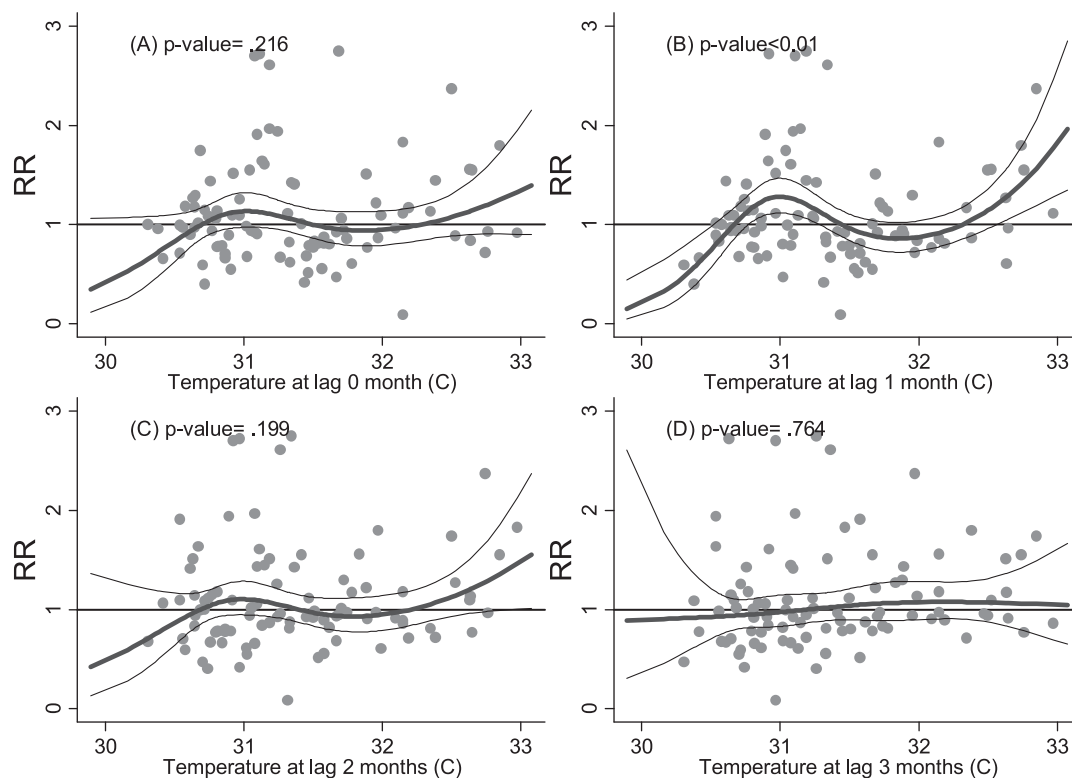


Fig. 2. Relationship between relative risk (RR) of diarrhea scaled to the mean monthly number of outpatients in Pohnpei and maximum temperature (shown as a 3 d.f. natural cubic spline) at lags of 0, 1, 2 and 3 months. The center line in each graph shows the estimated spline curve, and the upper and lower lines represent the 95% confidence limits. P-values represent the level of significance of the association between diarrhea and temperature.

ment for FSM.

Some important notes on the abovementioned categories of “climate-sensitive health risks” are as follows: with respect to vector-borne diseases, the only long-term data available for analysis was for dengue fever, which has been known to exist in FSM since at least the early 1990s [15], despite the fact that, at least in recent years, FSM has been plagued by other arboviruses including Zika virus [17] and chikungunya. FSM has also long been considered endemic for lymphatic filariasis, although the burden of this disease is decreasing, as elsewhere in the Pacific, due to mass drug administration and vector control programs [18]. FSM is not currently one of the PICs considered endemic for malaria; while the possibility remains that will climate change will affect the geographic range of the malaria vector, causing intrusion into non-endemic countries, this is currently considered to be a relatively low risk for FSM.

Secondly, “diarrheal illness” is a broad category of disease which obviously is not limited to infectious pathogens; nor are the infectious aetiologies limited to those transmitted via food and water (i.e. the modes of transmis-

sion considered most likely to be sensitive to environmental perturbations). Nevertheless, given the significant burden of disease due to diarrheal illness in FSM, particularly in children under five [19] and the strong evidence linking diarrheal illness to climatic factors such as temperature, rainfall, ENSO cycles and hydrometeorological disasters in the Pacific region and elsewhere in the world [20–25], it was considered justifiable to aggregate diarrheal illnesses for the purposes of this analysis.

As a final note, the category of “respiratory disease” was not included in this study focusing on climate-sensitive infectious diseases due to the fact that, while it may be assumed that this category includes respiratory infections (both acute illness like influenza and pneumonia, and chronic infections such as tuberculosis), it also includes non-infectious illnesses such as asthma and chronic obstructive airways disease. The latter constitute a significant cause of morbidity and mortality in FSM, particularly in adults [19], and while obstructive airways diseases, including asthma, may certainly be considered sensitive to changes in climate [26–28], as a non-communicable disease (NCD) it has not been included in this infectious

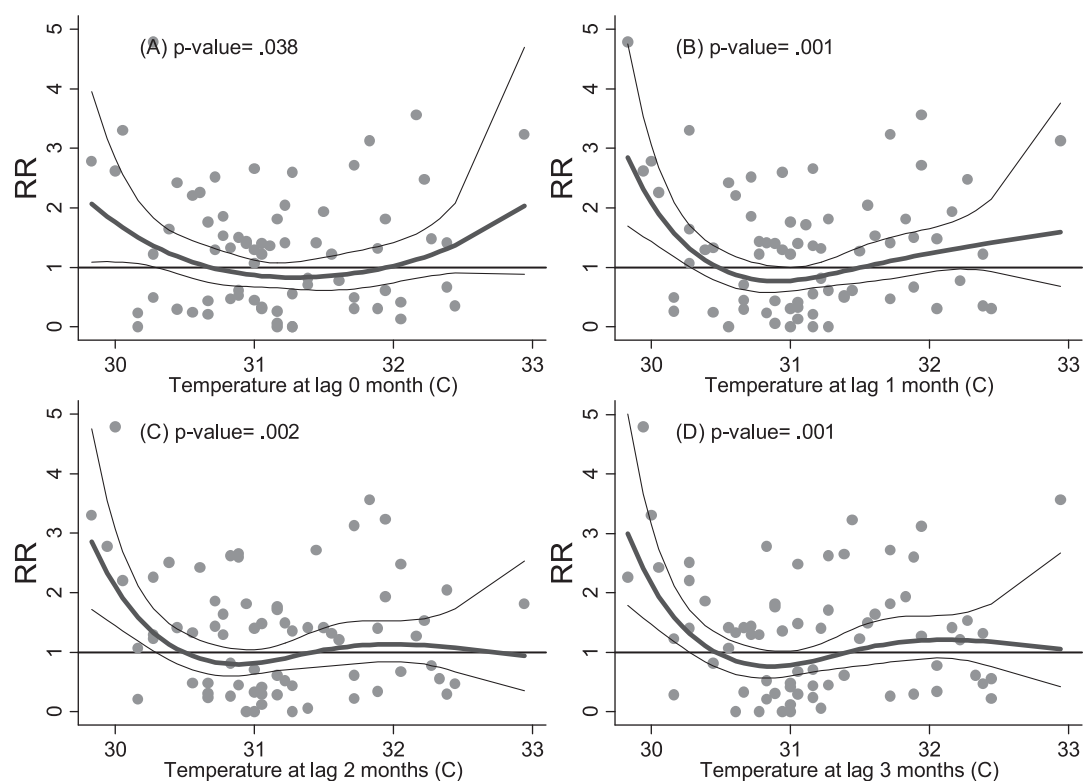


Fig. 3. Relationship between relative risk (RR) of diarrhea scaled to the mean monthly number of outpatients in Kosrae and maximum temperature (shown as a 3 d.f. natural cubic spline) at lags of 0, 1, 2 and 3 months. The center line in each graph shows the estimated spline curve, and the upper and lower lines represent the 95% confidence limits. P-values represent the level of significance of the association between diarrhea and temperature.

disease-focused paper. The same principle applies to skin diseases: it was not deemed feasible or useful to attempt to differentiate infectious and non-infectious skin disorders for the purposes of this paper.

The outcomes of the climate change and health vulnerability assessment in FSM are broadly consistent with those of other PICs [12, 29, 30], with relatively high priorities given to climate-sensitive infectious diseases, but concern was also raised regarding the prospect of climate change-induced impacts on NCDs, malnutrition, ciguatera, mental health, the health consequences of extreme weather events and disruptions to health and social services.

A summary of the overall climate change and health vulnerability and adaptation assessment process and key findings for FSM and thirteen other PICs can be found in a forthcoming WHO report entitled “Human Health and Climate Change in Pacific Small Island States”, to be launched in late 2014.

With respect to climate-sensitive infectious diseases and their relationship with climate in the context of FSM, the paucity of relevant disease data limited opportunities for the analysis described above and efforts to demonstrate

statistically significant associations between climate variables and the burden of the pre-eminent diseases of concern in FSM (diarrheal illness, vector-borne diseases and leptospirosis).

Nevertheless, there is abundant evidence from elsewhere in the region and around the world supporting the “climate-sensitivity” of these diseases and vindicating their inclusion among the highest priority climate-sensitive health risks in FSM, despite the fact that dengue fever and leptospirosis currently represent relatively small burdens of disease in the country.

Vector-borne diseases in general, and dengue fever in particular, have been shown to be exquisitely sensitive to hydrometeorological phenomena, including temperature, rainfall, humidity and ENSO [31–37], including in the Pacific region [38, 39], where recent attention has shifted towards the potential for climate-based early warning systems to minimize the impact of dengue fever epidemics [40].

In the case of leptospirosis, the links with ecological and meteorological factors are also relatively well-established [41–43], the burden of disease in FSM is be-

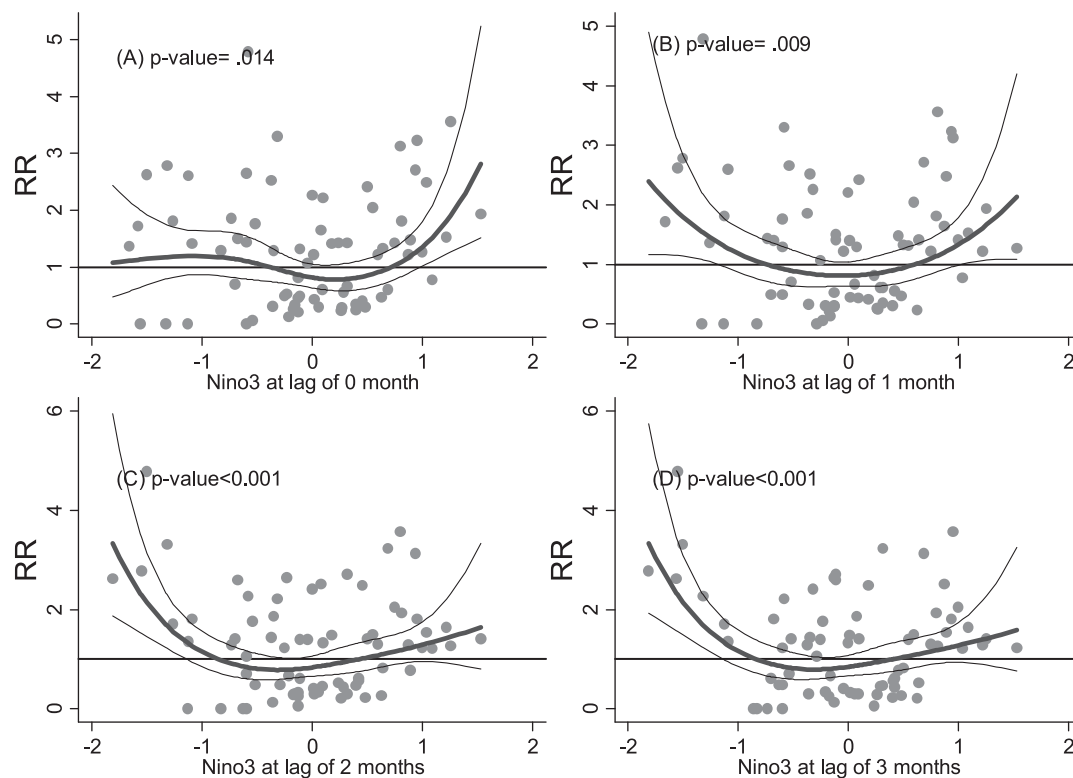


Fig. 4. Relationship between relative risk (RR) of diarrhea scaled to the mean monthly number of outpatients in Kosrae and Nino3 (shown as a 3 d.f. natural cubic spline) at lags of 0, 1, 2 and 3 months. The center line in each graph shows the estimated spline curve, and the upper and lower lines represent the 95% confidence limits. P-values represent the level of significance of the association between diarrhea and Nino3.

coming more clear [44], and the potential for early warning systems is gaining attention in the Pacific.

There is a similarly strong case to be made for the climate-sensitivity of diarrheal illness, as pointed out above. Although the pathways by which factors such as temperature, rainfall, ENSO and extreme events may affect the multiple pathogens causing infectious diarrhea create a complex aetiological picture [20, 24, 45–49], as shown by our results, a significant association can be observed between climatic factors such as temperature and the incidence of diarrheal disease, at least in Pohnpei and Kosrae states. This is relevant in FSM, and neighbouring Micronesian countries where both food- and water-borne pathogens have been known to cause large outbreaks of diarrheal illness in recent years [50, 51].

The lack of robust, long-term data on these three categories of climate-sensitive infectious diseases limited the extent to which detailed “exposure-response” models could be constructed for each of the four states. Additionally, the heterogeneity of the climate-disease relationships precluded, at least in part, the potential for aggregation and/or averaging at the national level. Nevertheless, it was

still deemed useful to consider, at least in a general, qualitative sense, the current and likely increased future climate change-attributable burden of these climate-sensitive infectious diseases in FSM, with respect to the opportunity for implementation of various adaptation strategies at the local, state and national levels.

The recommendations for health sector adaptation in relation to these three high-priority climate-sensitive infectious diseases in FSM include:

- community education and health promotion campaigns (e.g. on preventive behaviours such as protection against mosquito bites or contact with contaminated water and soil, including the risk inherent in cultural practices such as communal consumption of *sakau* [kava]);
- distribution of household equipment such as mosquito nets, safe water storage containers and water testing and treatment kits;
- increased recruitment and training of public and environmental health officers in the areas of water and food safety, animal health, vector surveillance and outbreak response;
- expansion of public and environmental health surveil-

lance and control activities to outer islands (currently neglected due to lack of sufficient resources);

- policy, legislative and regulatory measures targeting water and food safety, mosquito control (particularly habitat eradication) and improved hygiene and management of domestic livestock (particularly pigs);
- scale-up of diagnostic capacity, including improved microbiological capabilities, and increased use of rapid test kits for dengue fever and leptospirosis;
- health professional capacity-building in the fields of diagnosis, management and prevention of these climate-sensitive infectious diseases, as well as in applied environmental epidemiological techniques and the use of environmental health indicators in relation to climate and health [52];
- increased research on the epidemiology, burden of disease and climate-sensitivity of infectious diseases in FSM and elsewhere in Micronesia and the wider Pacific region; and
- consideration of the use of climate-based early warning systems for infectious diseases in FSM.

The latter recommendation regarding climate-based early warning systems (CBEWS) is common in the literature on climate change and health adaptation [53–57]. In FSM, this process is clearly impeded by the abovementioned data and model constraints. However, even with the limited data and models available for infectious diseases in FSM, it may be possible to construct a CBEWS for diarrheal disease based on the analysis and results described in this paper.

With reference to Figure 4, for example, it can be seen that the relative risk (RR) of diarrheal incidence in Pohnpei appears to increase beyond a temperature threshold of approximately 32.5 degrees Celsius in the previous month. It thus could prove feasible for a collaboration between the WSO and Pohnpei Department of Health Services to establish a mechanism for the issuing of alerts when the average maximum temperature in a given month, or four-week sliding window, reaches 32.5 degrees, which triggers a “surge” response of public and environmental health interventions targeting, for example, water and food safety and community health promotion. The efficacy of such interventions could then be analyzed epidemiologically, and the exposure-response models updated, as the time-series of climate and disease data is extended over time.

Apropos of the latter recommendation, it should also be pointed out that all of the analyses and models discussed above could and should be updated over time, and the NCCCHAP—including the theory and assumptions contained within it—should undergo similar reiterations to in-

corporate contemporary data and improved knowledge of the associations and implications of climate change and the high-priority climate-sensitive infectious diseases in FSM.

CONCLUSIONS

Infectious diseases were identified as among the highest priority climate-sensitive health risks of concern in FSM as part of the national climate change and health vulnerability assessment and adaptation planning process. Specifically, diarrheal disease, dengue fever (and other vector-borne diseases) and leptospirosis were considered to represent high risks with respect to future climate change-attributable burdens of disease in FSM.

Analysis of the available data on historical climate and cases of infectious diseases, although limited, yielded some potentially useful associations between climate variables and diarrheal disease in particular, which may have application in the context of a climate-based early warning system and the potential for public and environmental health interventions to limit the impact of near-term epidemics.

Adaptation strategies recommended in the FSM National Climate Change and Health Action Plan similarly prioritize climate-sensitive infectious diseases; successful implementation of any number of these measures may reduce or avert the most severe detrimental effects of climate change on these and other infectious diseases and their impact on the health of communities in FSM and the wider Micronesia and Pacific regions.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. Woodward A, Hales S, Weinstein P. Climate change and human health in the Asia Pacific region: who will be most vulnerable? *Clim Res* 1998; 11: 31–38.
2. Ebi KL, Lewis ND, Corvalan C. Climate Variability and Change and Their Potential Health Effects in Small Island States: Information for Adaptation Planning in the Health Sector. *Environ Health Perspect* 2006; 114: 1957–1963.

3. Patz Ja, Campbell-Lendrum D, Holloway T, et al. Impact of regional climate change on human health. *Nature* 2005; 438: 310–317.
4. World Health Organization, Western Pacific Regional Office, Manila P. Regional Framework for Action to Protect Human Health from Effects of Climate Change in the Asia-Pacific Region. Manila, Philippines: Western Pacific Regional Office; 2007. pp. 1–4.
5. WHO and Secretariat for the Pacific Community. *Madang Commitment* 2009; 13–14.
6. Program PCCS. Climate Change in the Pacific: Scientific Assessment and New Research - Country Report for Kiribati. 2011, Two.
7. Ebi KL, Kovats RS, Menne B. An Approach for Assessing Human Health Vulnerability and Public Health Interventions to Adapt to Climate Change. *Environ Health Perspect* 2006; 1930–1934.
8. Wardekker JA, de Jong A, van Bree L, et al. Health risks of climate change: An assessment of uncertainties and its implications for adaptation policies. *Environ Health* 2012; 11: 67.
9. Patz J, Campbell-Lendrum D, Gibbs H, et al. Health impact assessment of global climate change: expanding on comparative risk assessment approaches for policy making. *Annu Rev Public Health* 2008; 29: 27–39.
10. Haines A, Kovats RS, Campbell-Lendrum D, et al. Climate change and human health: impacts, vulnerability and public health. *Public Health* 2006; 120: 585–596.
11. Kovats R, Ebi K, Menne B. Methods of assessing human health vulnerability and public health adaptation to climate change. *Pan Am Health* 2003.
12. Spickett JT, Katscherian D, McIver L. Health Impacts of Climate Change in Vanuatu: An Assessment and Adaptation Action Plan. *Glob J Health Sci* 2013; 5: 42–53.
13. Spickett JT, Brown HL, Katscherian D. Adaptation strategies for health impacts of climate change in Western Australia: Application of a Health Impact Assessment framework. *Environ Impact Assess Rev* 2011; 31: 297–300.
14. Bhaskaran K, Gasparrini A, Hajat S, et al. Time series regression studies in environmental epidemiology. *Int J Epidemiol* 2013; 42: 1187–1195.
15. Savage HM, Fritz CL, Rutstein D, et al. Epidemic of dengue-4 virus in Yap State, Federated States of Micronesia, and implication of *Aedes hensilli* as an epidemic vector. *Am J Trop Med Hyg* 1998; 58: 519–524.
16. Centers for Disease Control and Prevention (CDC). Dengue Outbreak—Federated States of Micronesia, 2012–2013. *MMWR Morb Mortal Wkly Rep* 2013; 62: 570–573.
17. Duffy MR, Chen T-H, Hancock WT, et al. Zika virus outbreak on Yap Island, Federated States of Micronesia. *N Engl J Med* 2009; 360: 2536–2543.
18. Burkot T, Ichimori K. The PacELF programme: will mass drug administration be enough? *Trends Parasitol* 2002; 18: 109–115.
19. Samo M, Elymore A. Mortality analysis of registered deaths in the FSM from 1990–2003. *Pac Health Dialog* 2010; 16: 115–122.
20. Wu J, Yunus M, Streatfield PK, et al. Association of climate variability and childhood diarrheal disease in rural Bangladesh, 2000–2006. *Epidemiol Infect* 2014; 142: 1859–1868.
21. Hashizume M, Armstrong B, Hajat S, et al. Association between climate variability and hospital visits for non-cholera diarrhea in Bangladesh: effects and vulnerable groups. *Int J Epidemiol* 2007; 36: 1030–1037.
22. Singh RB, Hales S, de Wet N, et al. The influence of climate variation and change on diarrheal disease in the Pacific Islands. *Environ Health Perspect* 2001; 109: 155–159.
23. Leclerc H, Schwartzbrod L, Dei-Cas E. Microbial agents associated with waterborne diseases. *Crit Rev Microbiol* 2002; 28: 371–409.
24. Hashizume M, Wagatsuma Y, Faruque ASG, et al. Factors determining vulnerability to diarrhea during and after severe floods in Bangladesh. *J Water Health* 2008; 6: 323–332.
25. Checkley W, Epstein LD, Gilman RH, et al. Effects of El Niño and ambient temperature on hospital admissions for diarrheal diseases in Peruvian children. *Lancet* 2000; 355: 442–450.
26. Jouret J. Respiratory implications of a changing climate. *Lancet Respir Med* 2013; 1(3): 196.
27. Beggs PJ, Bambrick HJ. Is the Global Rise of Asthma an Early Impact of Anthropogenic Climate Change? *Environ Health Perspect* 2005; 113: 915–919.
28. Takaro TK, Knowlton K, Balmes JR. Climate change and respiratory health: current evidence and knowledge gaps. *Expert Rev Respir Med* 2013; 7: 349–361.
29. McIver L, Woodward A, Davies S, et al. Assessment of the Health Impacts of Climate Change in Kiribati. *Int J Environ Res Public Health* 2014; 11(5): 5224–5240.
30. McIver L. Climate change and health in the Pacific: cause for concern; opportunities for adaptation. *Inform'Action* 2012; 36: 3–6.
31. Hii YL, Zhu H, Ng N, et al. Forecast of Dengue Incidence Using Temperature and Rainfall. *PLoS Negl Trop Dis* 2012; 6: e1908.
32. Pinto E, Coelho M, Oliver L, et al. The influence of climate variables on dengue in Singapore. *Int J Environ Health Res* 2011; 21: 415–426.
33. Morin CW, Comrie AC, Ernst K. Climate and Dengue Transmission: Evidence and Implications. *Environ Health Perspect* 2013; 121: 1264–1272.
34. Cheong Y, Burkart K, Leitão P, et al. Assessing Weather Effects on Dengue Disease in Malaysia. *Int J Environ Res Public Health* 2013; 10: 6319–6334.
35. Xu H.-Y., Fu X, Lee LKH, et al. Statistical Modeling Reveals the Effect of Absolute Humidity on Dengue in Singapore. *PLoS Negl Trop Dis* 2014; 8: e2805.
36. Rosa-Freitas MG, Schreiber KV, Tsouris P, et al. Associations between dengue and combinations of weather factors in a city in the Brazilian Amazon. *Rev Panam Salud*

- Publica 2006; 20: 256–267.
37. Vu HH, Okumura J, Hashizume M, et al. Regional Differences in the Growing Incidence of Dengue Fever in Vietnam Explained by Weather Variability. *Trop Med Health* 2014; 42: 25–33.
 38. Banu S, Hu W, Hurst C, et al. Dengue transmission in the Asia-Pacific region: impact of climate change and socio-environmental factors. *Trop Med Int Heal* 2011; 16: 598–607.
 39. Hales S, Weinstein P, Souares Y, et al. El Niño and the dynamics of vectorborne disease transmission. *Environ Health Perspect* 1999; 107: 99–102.
 40. Descloux E, Mangeas M, Menkes CE, et al. Climate-based models for understanding and forecasting dengue epidemics. *PLoS Negl Trop Dis* 2012; 6: e1470.
 41. Desvars A, Jégo S, Chiroleu F, et al. Seasonality of human leptospirosis in Reunion Island (Indian Ocean) and its association with meteorological data. *PLoS One* 2011; 6: e20377.
 42. Lau CL, Dobson AJ, Smythe LD, et al. Leptospirosis in American Samoa 2010: epidemiology, environmental drivers, and the management of emergence. *Am J Trop Med Hyg* 2012; 86: 309–319.
 43. Ivanova S, Herbreteau V, Blasdell K, et al. *Leptospira* and rodents in Cambodia: environmental determinants of infection. *Am J Trop Med Hyg* 2012; 86: 1032–1038.
 44. Colt S, Pavlin BI, Kool JL, et al. Human leptospirosis in The Federated States of Micronesia: a hospital-based febrile illness survey. *BMC Infect Dis* 2014; 14: 186.
 45. Braks M, Husman Ade R. Dimensions of Effects of Climate Change on Water-Transmitted Infectious Diseases. *Air Water Borne Dis* 2013; 2: 1–8.
 46. Cann KF, Thomas DR, Salmon RL, et al. Extreme water-related weather events and waterborne disease. *Epidemiol Infect* 2013; 141: 671–686.
 47. Brown L, Murray V. Examining the relationship between infectious diseases and flooding in Europe: A systematic literature review and summary of possible public health interventions. *Disaster Heal* 2013; 1(2): 117–127.
 48. Hashizume M, Chaves LF, Faruque ASG, et al. A Differential Effect of Indian Ocean Dipole and El Niño on Cholera Dynamics in Bangladesh. *PLoS One* 2013; 8: e60001.
 49. Hashizume M, Armstrong B, Hajat S, et al. The Effect of Rainfall on the Incidence of Cholera in Bangladesh. *Epidemiology* 2008; 19: 103–110.
 50. Johnson E, Jim R, Pavlin BI. Hepatitis A in Pohnpei State, Federated States of Micronesia, 2008–2009. *Pac Health Dialog* 2010; 16: 91–97.
 51. Thein C, Trinidad R, Pavlin B. A Large Foodborne Outbreak on a Small Pacific Island. *Pacific Heal Dialogue* 2010; 16(1): 75–80.
 52. Hambling T, Weinstein P, Slaney D. A review of frameworks for developing environmental health indicators for climate change and health. *Int J Environ Res Public Health* 2011; 8: 2854–2875.
 53. Chaves LF, Pascual M. Comparing models for early warning systems of neglected tropical diseases. *PLoS Negl Trop Dis* 2007; 1: e33.
 54. Lowe R, Bailey TC, Stephenson DB, et al. The development of an early warning system for climate-sensitive disease risk with a focus on dengue epidemics in Southeast Brazil. *Stat Med* 2013; 32: 864–883.
 55. Ebi KL, Lindgren E, Suk JE, et al. Adaptation to the infectious disease impacts of climate change. *Clim Change* 2012; 118: 355–365.
 56. World Health Organization. Protecting health from climate change: Global research priorities. *World Heal Organ Public Heal*. Available: <http://www.who.int/globalchange/publications/9789241598187/en/>
 57. Ebi K, Rocklov J. Climate change and health modeling: horses for courses. *Glob Health Action* 2014; 7: 24154.

Chapter Six

Paper 3: Health impacts of climate change in Vanuatu:
an assessment and adaptation action plan

Prelude

The paper in this chapter describes the relatively novel methods employed in the vulnerability assessment and adaptation planning process in Vanuatu. In Vanuatu, Solomon Islands and Nauru, a comprehensive, consensus-building approach was used, in a model adapted from the Environmental Health Impact Assessment (EHIA) literature. The methodology conformed to standard HIA frameworks – incorporating screening, scoping, profiling, assessing and managing risk, making decisions and evaluating outcomes – but was modified to incorporate the longer timelines and cross-cutting nature of the health hazards posed by climate change. Such a modified EHIA approach had been piloted successfully in Western Australia by the consultant team engaged to guide the work in these three Pacific island countries.

This highly consultative technique, utilising a systematic, step-wise method of scenario-planning that considered the multiple aspects of health vulnerability across society, proved very useful in the Pacific island context, where the scarcity of data and analytical expertise meant that opportunities for employing quantitative methodologies, such as those described in the previous chapter, were often limited.

The candidate's estimated proportional contributions to this paper were as follows:

Research design:	50%
Analysis and interpretation:	50%
Authorship of paper:	50%

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Health Impacts of Climate Change in Vanuatu: An Assessment and Adaptation Action Plan

Jeffery T Spickett¹, Dianne Katscherian¹ & Lachlan McIver²

¹ Faculty of Health Sciences, School of Public Health and Curtin Innovation Research Institute (CHIRI), Curtin University, Perth, Western Australia, Australia

² WHO South Pacific Office, Suva, Republic of Fiji

Correspondence: Jeff Spickett, School of Public Health, Curtin University, Kent Street, Bentley, Western Australia 6102, Australia. Tel: 61-892-662-763. E-mail: J.Spickett@curtin.edu.au

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Abstract

Climate change is one of the greatest global challenges and Pacific island countries are particularly vulnerable due to, among other factors, their geography, demography and level of economic development.

A Health Impact Assessment (HIA) framework was used as a basis for the consideration of the potential health impacts of changes in the climate on the population of Vanuatu, to assess the risks and propose a range of potential adaptive responses appropriate for Vanuatu. The HIA process involved the participation of a broad range of stakeholders including expert sector representatives in the areas of bio-physical, socio-economic, infrastructure, environmental diseases and food, who provided informed comment and input into the understanding of the potential health impacts and development of adaptation strategies.

The risk associated with each of these impacts was assessed with the application of a qualitative process that considered both the consequences and the likelihood of each of the potential health impacts occurring. Potential adaptation strategies and actions were developed which could be used to mitigate the identified health impacts and provide responses which could be used by the various sectors in Vanuatu to contribute to future decision making processes associated with the health impacts of climate change.

Keywords: health impact assessment, climate change, adaptation, Vanuatu

1. Introduction

That climate change is already having an impact on the global burden of morbidity and mortality has been stated in the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment report, which also indicates that these effects are likely to increase all around the globe (IPCC, 2007). The nature and magnitude of climate change will determine the extent and nature of future health impacts, so it is crucial that strategies to mitigate climate change are widely implemented. However, irrespective of the implementation of mitigation measures, health impacts from climate change will ensue and therefore it is very important that adaptation measures are developed and implemented to ensure that adverse impacts are minimal (Cambell-Lendrum et al., 2006).

Although the changing climate is a worldwide issue, it will not be experienced uniformly across the world and many local and regional adaptation measures will need to be developed and implemented. It is crucial for the health of the community that adaptation strategies are implemented where the adverse health impacts that pose the greatest potential risk, and/or where the benefits to health can be maximised.

Understanding the relationship between climate variability, the environment and human health can enable us with some uncertainty, to predict the likely and plausible climate change-attributable impacts on health, and thus plan effective adaptation strategies (WHO, 2003a). Health impact pathways from climate change were first articulated by a special WHO Working Group in 1990; these pathways can occur as a result of direct or indirect exposures (WHO, 1990). Direct exposures refer to the immediate health impacts that can occur as a direct result of a climate variable, for example heat waves, fires, floods whereas indirect exposures occur when climate change affects various environmental parameters such as air, water, food quality, food production and disease vectors, or social parameters such as changes to population distribution and economic variables (IPCC, 2007). Pathways between changes in the climate and the subsequent impact on health for indirect exposures typically

include a number of steps, many of which are not the responsibility of the health sector and call for a cross-sectoral, collaborative approach.

Potential points of vulnerability can occur at different steps in the health impact pathway and each step can present an opportunity for adaptation. Vulnerability can be considered as the degree to which a system is susceptible to, or unable to cope with, the adverse effects of climate change (IPCC, 2001) and is a function of three major factors; exposure to climate factors, sensitivity to change, and adaptive capacity. Exposure to climate factors depends on location and activities undertaken; sensitivity relates to the way the individual, community or system responds to climate change. Adaptive capacity is the general ability of institutions, systems and individuals to adjust to changes that occur as a result of climate change and the ability to take advantage of opportunities and to cope with the consequences. Many adaptation strategies will be designed to increase our capacity to adapt to the effects of climate change.

The involvement of a range of sectors in planning and implementing mitigation and adaptation strategies is important to optimise our responses to the various risk factors that determine our overall vulnerability. A comprehensive assessment of vulnerability is particularly important, as the main benefits from adaptation measures will occur when they focus on critical points in the pathway and/or at vulnerable sectors of the population.

2. Climate Change and Health in the Pacific

In 2009, the Health Ministers of the Pacific island countries held their biennial meeting in Madang, Papua New Guinea and included discussion on the impacts of climate change on health. The Ministers recognised that Pacific island countries are particularly vulnerable to climate change and identified several high-priority, climate-sensitive health risks common throughout the region (WHO, 2009). This initiative followed the dissemination of a pivotal WHO Regional Framework for Action document in 2008, which laid out key guidelines and core responsibilities for the health sector to protect communities from the health impacts of climate change in the Asia Pacific region (WHO, 2008).

In Vanuatu, as far back as 1999, in the country's Initial National Communication (INC) to the United Nations Framework Convention on Climate Change (UNFCCC) consideration was given to the potential for climate change-attributable health impacts to occur (INC, 1999). More recently, the health impacts of climate change in Vanuatu were outlined in the National Adaptation Programme of Action (NAPA, 2007). In 2010, the Vanuatu Ministry of Health (MoH) commenced a twelve-month project, supported by the World Health Organization (WHO) South Pacific, aimed at improving the understanding of the relationship between climate and health in Vanuatu and to develop adaptation strategies related to climate change and health. This research was undertaken to identify potential risks to health, to evaluate the risks to determine their relative priority and then to develop potential adaptation strategies to minimise the impacts on *ni-Vanuatu* communities.

3. Assessment of Climate Change Health Impacts

Health Impact Assessment (HIA) is a tool developed to consider potential health issues during planning stages of proposals using established systematic mechanisms to demonstrate factors that could affect health and to consider potential management options in response. HIA is commonly defined as "a combination of procedures, methods and tools by which a policy, program or project may be judged as to its potential effects on the health of a population, and the distribution of those effects within the population" (WHO 1999). HIA is an evidence-based process that aims to identify and examine both the positive and negative health impacts of activities and provide decision makers with information about how the activity may affect the health of people.

The HIA framework follows the format of:

- Screening
- Scoping
- Profiling
- Risk assessment
- Risk management
- Decision making
- Evaluation

HIA has mainly been used for the assessments of projects or developments. However it has been identified by

the World Health Organisation and others (Brown et al., 2011; Nelson, 2003; WHO, 2003b) that the HIA process provides an appropriate methodology by which the potential impacts of climate change could be initially assessed to support decision making, especially since it considers health equity (Patz et al., 2008). We developed an HIA framework that provided for the prediction of potential impacts based on a single possible scenario of future climatic conditions and biophysical changes in Western Australia (Spickett et al., 2011). The methodology was used as the basis for developing and implementing a process to develop potential adaptation strategies for health impacts from climate change in Vanuatu.

The health and well-being of the community is dependent on the activities of a range of private and public sectors including sectors such as environment, transport, energy supply, and food supply. Involvement of these sectors and the public in all stages of HIA provides stakeholders with the opportunity to engage with the activity and act collaboratively to share possible community benefits as well as to minimise potential future problems. The activities of these sectors impact on health and so need to be included in processes to determine risks and potential adaptation strategies.

4. Climate Change in Vanuatu

Vanuatu is an archipelago of approximately 80 islands with a land area of 12 335 square kilometres located south of the equator in the Western Pacific ocean. The predominantly Melanesian population of approximately 240 000 is growing at a rate of 2.3% per annum, and is expected to double by approximately 2030 (Ministry of Health Annual Report, 2010).

The economy is largely driven by tourism (which accounts for approximately 40% of Gross Domestic Product, (GDP)) and primary industries (agriculture, fisheries and forestry together account for roughly 15% of GDP).

Vanuatu's climate is tropical, with two distinct seasons – a warm, wet season and a cooler, dry season. The climate varies considerably from year to year, mainly due to the effects of the El Niño-Southern Oscillation (ENSO) system. The wet season often brings tropical cyclones: 94 intense storms passed within 400km of Port Vila from 1969 to 2010 (Pacific Climate Change Science Program, PCCSP, 2011).

The main climate change phenomena expected to occur in Vanuatu include (PCCSP, 2011):

- *increasing air and sea-surface temperatures*
 - o average air temperatures in Vanuatu are expected to increase by up to 1°C by 2030 and in the order of 2-3°C by 2090, depending on future greenhouse gas emissions scenarios.
- *altered rainfall patterns*
 - o most models predict drier dry seasons and wetter wet seasons for Vanuatu, as well as more “extreme/high” rainfall events.
- *less frequent but more intense cyclones*
- *sea-level rise*
 - o the recent rate of sea-level rise in Vanuatu has been between 4.7 and 6 millimetres per year and is expected to continue at this rate to 2030.
- *ocean acidification*

4.1 The Adaptation Project

The objectives of this research were to:

- identify the potential risks to health from climate change in Vanuatu;
- evaluate those risks to determine their respective priorities in terms of the likelihood of the event occurring and the severity of the potential impact on human health and safety; and
- propose a range of feasible adaptation options to avoid the most serious impacts of climate change on health in Vanuatu.

5. Methods

The HIA framework used incorporated the profiling to risk management components. The research was guided by a sequence of three steps: planning, implementation and development of adaptation strategies.

For this project, health was considered in broad terms with a range of determinants, as per the WHO definition of environmental health:

“Environmental health addresses all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours. It encompasses the assessment and control of those environmental factors that can potentially affect health. It is targeted towards preventing disease and creating health-supportive environments” (WHO, 2013a).

Participants were invited to participate based on their knowledge, expertise and access to data and information relevant to Vanuatu in the areas of:

- The bio-physical environment (water, air quality, ecosystems)
- The social and economic environment (e.g economy, mental health, communities and lifestyle, dislocation)
- The built environment and infrastructure (transport, energy, essential services)
- Environmental diseases (vectors, pests, communicable diseases)
- Food security and safety
- Disaster and management (extreme events)
- Risk assessment and management

An emphasis was placed on the inclusion of community participants with understandings of local circumstances and variability.

5.1 Planning

An inception process with representatives of several government sectors detailed a stepwise approach to enable systematic progress through each stage. Table 1 provides a summary of the steps in the process.

Table 1. Summary of the climate change and health assessment process

Stage	Process Component	Issues for inclusion
Preliminary	Development of Communication Strategy Development of a Stakeholder involvement Strategy	
1	Identification of climate variables	Creation of scenario for 2030
2	Identification of environmental impacts arising from climate change	Addressed through identification of changes to: Biophysical environment Social environments Infrastructure
3	Identification of potential health impacts	Identification of health impacts arising from environmental changes Identification of vulnerable: People/groups Regions Infrastructure Services Identifying/determining gaps in knowledge Understanding current coping (controls) capacity and limitations
4	Risk Assessment	Undertake risk assessments of the identified health impacts Identifying experts to assist: Risk assessments Specific fields
5	Risk prioritisation	List impacts according to level of risk Need to reach consensus based on expert knowledge

Stage	Process Component	Issues for inclusion
6	Development of adaptation responses	Use of range of adaptation responses provided. Should consider other adaptations applicable to home country Consideration of responses with respect to: General population Vulnerabilities Adequacy of control measures Other requirements Priorities for action
7	Action Plans (strategies required to implement adaptations)	For application in Vanuatu Need to identify roles and responsibilities

The research process generally followed the steps of a climate change and health vulnerability and adaptation assessment (Spickett et al., 2011) and was divided into the phases of:

- Identification of the potential health impacts of climate change;
- Stratification (ranking) of the climate-sensitive health issues according the risk each posed in the context of climate change;
- Identification of appropriate adaptation strategies to reduce the risks posed by each climate-sensitive health issue

5.2 Implementation

Focus group meetings were held with stakeholders from relevant sectors whose activities were identified as potentially influencing the health impacts from climate change and included senior representatives from most Government sectors responsible for policy development and implementation.

To identify potential health impacts the groups were provided with a scenario of potential changes in climate in Vanuatu in the year 2030 based on projections from PCCSP (Pacific Climate Change Science Program, 2011). Two important assumptions were then made for the entire project which were:

- 1) The year is 2030 and climate change projections have occurred
- 2) Only current management strategies for each health impact are taken into account

The group members then considered in the context of the determinants of health (WHO, 2013b), four major areas:

- Biophysical environment – impacts including water quality, air quality and biodiversity.
- Social environment - impacts including population displacement and mental health issues.
- Built environment - impacts related to services, infrastructure and economics, including resource availability and access to a range of health, emergency and other services.
- Environmental diseases and food – impacts related to production of food, vector-borne and food-borne disease and other environmental diseases.

The climate change effects were also divided into broad sections:

- Increase in severity &/or incidence of extreme events (tropical cyclones, storms, droughts and heatwaves)
- Increase in temperature
- Changes in rainfall (patterns and volume)
- Increase in sea-level

For each potential climate change the group then identified:

- potential impacts on health
- potential health impact pathways
- vulnerable groups

- current responses and limitations
- gaps in knowledge

A comparative measure of risk is essential for the prioritisation of adaptation measures. Participants with expertise in health or risk assessment undertook a qualitative risk assessment in their specific areas of knowledge to ascertain the level of risk to public health in Vanuatu.

The potential impacts were divided into the areas of:

- Extreme Events
- Temperature Increase and Related Changes
- Water-borne Disease and Water Quality
- Vector-borne diseases
- Air Quality
- Food-borne diseases
- Food Production
- Social Impact/Community Lifestyle-Dislocation, Mental Health

Impacts were assessed on a qualitative scale that considered the health consequences and the likelihood of the health impact occurring. The consequences of potential health impacts were considered in terms of the magnitude of the impact, the severity of the health impact, the number of people affected, the duration of the impact and the socio-economic implications. Likelihood ratings were rare, unlikely, possible, likely and almost certain. A rationale for rankings was recorded.

Risk assessment results were entered into a risk assessment matrix to assign each identified health impact a risk category of low, medium, high or extreme. Risk priority levels determined by each group were compared to improve parity across differing impacts types. Consensus regarding the final risk level was important to enable focus on high-level risks for the development of potential adaptation strategies.

The risk management stage of the project considered adaptation measures that could be applied to the potential health impacts with a risk ranking of medium or higher. A literature search had identified a list of potential adaptation measures and participants considered each measure for Vanuatu and added other measures where appropriate.

5.3 Adaptation Strategies

The adaptation measures were categorised as:

- Legislative or Regulatory
- Public Education or Communication
- Surveillance and Monitoring
- Ecosystem Intervention
- Infrastructure Development
- Technological/Engineering
- Medical Intervention
- Research/Further Information

Each adaptation measure was considered in the context of:

- Relevance for Vanuatu
- Current capacity inclusive of vulnerable groups/regions rated as; not in place (N); inadequate (I); being developed (D); or adequate (A)
- How adaptations could be implemented in Vanuatu (adjustment/modification of existing measures or the development of new measures)
- Identification of sectors that would be involved in the development and implementation of the adaptation strategies.

6. Results

The application of an HIA framework addressing climate change in Vanuatu provided:

- Identification of potential health impacts
- Identification of vulnerable groups
- Understanding of key current controls or coping strategies
- Determination of current knowledge and gaps
- Identification of linkages between sectors
- Assessment of risk associated with each impact
- Identification of opportunities for adaptation and responsible sectors

Health problems that may be affected by climate change in Vanuatu were identified. These include (but are not limited to):

- vector-borne diseases (eg. malaria, dengue fever, lymphatic filariasis)
- respiratory disease
- water-borne diseases
- malnutrition/food security
- food-borne diseases
- non-communicable diseases
- traumatic injuries and deaths (eg. from extreme weather events such as cyclones, floods)
- temperature-related illnesses
- mental health disorders
- skin conditions
- eye diseases

Based on feedback from expert participants, which included relevant evidential information and data, climate-sensitive health risks in Vanuatu were ranked as per the results in Table 2.

Table 2. Climate-sensitive health risks in Vanuatu

Risk category	Health issue
Extreme	Water-borne diseases
	Food-borne diseases
High	Vector-borne diseases
	Malnutrition
	Non-communicable diseases
	Temperature-related illnesses
	Occupation-related illnesses
Medium	Respiratory infections
	Skin conditions
	Eye diseases
	Mental health disorders
	Traumatic injuries and deaths

The highest level of risk was assigned to health impacts from water-borne and food-borne diseases.

Common themes of vulnerability across a wide range of health impacts were considered under the categories;

regional, economic, social and infrastructure and services. These highlighted that existing health vulnerabilities are likely to be exacerbated by climate change.

Table 3 lists potential adaptation strategies proposed to manage the climate-sensitive health risks for the extreme risk categories. Adaptation strategies were also developed for the health risks in the high category but they are not presented here.

Table 3. Potential adaptation strategies and actions for priority climate-sensitive health risks in Vanuatu

Strategies	Actions
EXTREME RISK – Water Borne Diseases	
Legislative or Regulatory	<ul style="list-style-type: none"> - Develop policy for water storage design and maintenance - Review, amend and enforce existing relevant legislation such as the Public Health Act and Water Resource Management Act - Finalize and enforce policies and standards for water management - Fast track the completion of the National Building Code and mainstream Climate Change and Water considerations - Implementation of National Water Strategy 2008-2018.
Public Education & Communication	<ul style="list-style-type: none"> - Develop water hygiene communication strategy - Strengthen community participation in health promotion activities - Mainstream climate change and water hygiene into national curricula for schools and other educational programs at all levels
Surveillance & Monitoring	<ul style="list-style-type: none"> - Strengthen water and waste water quality monitoring - Strengthen water quantity monitoring
Ecosystem Intervention	<ul style="list-style-type: none"> - Identify and map water catchment areas - Develop water shed management plans - Protect Water Source areas/Catchment areas.
Infrastructure Development	<ul style="list-style-type: none"> - Strengthen and expand National Water Laboratory capacity - Establish and/or upgrade public waste water treatment plant in major urban centres - Increase and expand distribution of health facilities to remote areas
Technology or Engineering	<ul style="list-style-type: none"> - Improve storm water drainage systems - Climate proof designs for public facilities - Use renewable energy technologies to power health facilities - Establish appropriate waste management processes - Establish and manage stock pile of medical & water storage supplies for national health response
Health Intervention	<ul style="list-style-type: none"> - Mainstream climate change and water hygiene into National Health Disaster Plan - Deployment of more doctors to rural health centres
Research/Information	<ul style="list-style-type: none"> - Assessments of water and climate change issues and identification of vulnerable communities - Establish relationship between ENSO, temperature/precipitation and incidences of water borne diseases - Strengthen and update Health Information Systems – particularly water hygiene and Environmental Health diseases - Complete national water resource inventory - Conduct national environmental health survey
Capacity Building	<ul style="list-style-type: none"> - Establish and implement national strategy for water hygiene Strengthen capacity to develop and implement education and training curricula

EXTREME RISK – Food Borne Diseases

S1 Legislative or Regulatory	<ul style="list-style-type: none"> - Review, Amend and Enforce Food Control Act and regulations - Development of National Food Standards - Develop National Food Security Framework
S2 Public Education & Communication	<ul style="list-style-type: none"> - Develop Food Safety Communication strategy - Mainstream climate change and food safety into National curricula - Strengthen health promotion at all levels
Surveillance & Monitoring	<ul style="list-style-type: none"> - Develop surveillance system for food borne disease/health information - Strengthen existing laboratory capacities - Establish Food Import/Export Inspection Systems.
Ecosystem Intervention	<ul style="list-style-type: none"> - Protect Fishing grounds/Agricultural land - Establish aquaculture
Infrastructure Development	<ul style="list-style-type: none"> - Establish National Food Analytical facilities. - Improve food storage , transport and marketing facilities to remote areas - Improve food-processing facilities. - Provide assistance to street vendors in establishing safe areas for handling food.
Technology or Engineering	<ul style="list-style-type: none"> - Develop and implement Good Agriculture Practices - Provide support for local and traditional processes and practices - Introduce renewable energy technologies for food processing
Health Intervention	<ul style="list-style-type: none"> - Review and update the National Health Workers manual on treatment of Diarrheal diseases and other dehydration conditions. - Deployment of more doctors to rural health centres
Research/Information	<ul style="list-style-type: none"> - Strengthen existing data collection procedures under the Health Information System - Establish links between climate parameters and food poisoning/intoxication and specific pathogens and toxins - Research traditional treatments for Fish Poisoning - Conduct a National Food Safety/Nutrition Survey.
Capacity Building	<ul style="list-style-type: none"> - Strengthen and enhance enforcement/inspection capacities - Increase Human resource capacities in the Environmental Health Unit.

7. Discussion

The main potential health impacts from climate change in Vanuatu tended to emphasise the public health risks that are dominant in a society experiencing the so-called “epidemiological transition”, with relatively high burdens of both infectious and non-communicable diseases. It is important to note that, in the case of Vanuatu as in many other countries and communities, climate change will not necessarily bring new threats, but rather act as an “amplifier” or “multiplier” of existing health problems (that is, in the absence of effective adaptation strategies).

A major difficulty was dealing with the significant uncertainties. Typical quantitative risk assessment procedures rely on well-documented risks and, with the availability of adequate data reasonably good risk estimates can be calculated. Making judgements about risks to human health is more difficult because of the uncertainty from interacting climatic variations and consequential environmental changes. In addition, there were uncertainties about the proposed adaptations as workshop participants were not fully aware of the status of the current circumstances of the proposed adaptation measures for reducing health impacts in Vanuatu.

The levels of uncertainty surrounding consequences and/or likelihood of the potential health impacts were typically higher for indirect and social health impacts, often because of the complexity of the relationship between the climate variable and the health impact, and knowledge gaps about this relationship. The

vulnerabilities of different groups within the population were also considered. In general a higher level of conservatism was applied for those health impacts with a high degree of uncertainty.

The levels of urgency considered necessary to address the climate-sensitive health issues and progress adaptation options are summarised in Table 4.

Table 4. Management of climate-sensitive health risks

Risk Levels for Health	Description of Management Action
Extreme	Risks require urgent attention at the most senior level and cannot be simply accepted by the community
High	Risks are the most severe that can be accepted by the community and need planned action
Medium	Risks can be expected to be part of normal circumstances but maintained under review by appropriate sectors
Low	Risks will be maintained under review but it is expected that existing controls will be sufficient and no further action will be required to treat them unless they become more severe

In most, if not all, of the adaptation options listed, there are common actions that include the need for:

- increased capacity both in human resources and equipment and other support;
- further information on the health impacts of climate change, including incorporation of these considerations into the training curricula of health professionals in Vanuatu;
- community education from primary school onwards on the potential health impacts of climate change and the need for adaptation strategies;
- improved collection, collation, storage and analysis of data on health status in the community;
- inter-sectoral collaboration; and
- improved standards and better enforcement of current regulations.

It was recommended that the adaptations for the “extreme” and “high” risk categories be given priority consideration through a whole-of-government approach. The next stages would be to implement the adaptation measures in each area via a lead agency or sector together with other relevant sectors. The health sector should be included in all groups including anticipation of any unexpected or unforeseen adverse health impacts. The Health Impact Assessment (HIA) process would provide a framework for this process to occur.

Responses should determine whether each of the proposed adaptations require further justification and can be implemented readily or if further analysis is required to evaluate the nature of the risk and determine the most appropriate response actions. Some risks may need to be accepted if there is no cost-effective adaptation measure or the risk is considered insignificant.

The process used in this project should be repeated, in a modified form, as new information on the monitoring of climates parameters, predicted climate changes and the predicted adverse impacts on human health become available.

The limitations of this project have been recognised. Fussell (2008) notes that there are many aspects of climate change impacts that have unfamiliar components such as the spatial scale, its long-term horizon and its complex spatial and time pattern. The use of a conservative scenario for 2030 was considered most appropriate for this investigation. For a more rigorous assessment of the potential health impacts of climate change, there is a need to ensure that outcomes are reassessed as climate predictions change, downscaled climate data for specific regions are developed and utilised and that all potential affected sectors are informed and consulted during all stages.

In considering the adaptation activities it is important that, for every action, the potential co-benefits (for health) are also considered.

8. Conclusions

This research has identified many potential adaptation measures to reduce or mitigate the impact of climate change on human health in Vanuatu that consider the current level of development in the country. The possible events that could impact on health have been identified in terms of the estimated level of risk and the estimated current level of capacity response. This assessment should allow sectors to make judgements about risks and appropriate responses that require attention in the short term, those that can be set aside for later attention and those where more information is needed. The results are expected to be used by decision makers to provide direction on planning for the short, medium and long term.

In the final analysis it may be that some risks will need to be accepted because there is no cost effective adaptation measure or the risk to human health is considered to be insignificant in Vanuatu. The level of risk assessment used in this project did not require a detailed understanding of climate change to provide a general indication of the types of adaptation responses needed to reduce the adverse effects on health which may arise. However, further information is needed in order to progress to a more detailed and accurate assessment of current adaptation measures. The activities and requirements of specific sectors will need a greater level of general awareness and increased capacity to more accurately predict the impacts of climate changes on health and to develop and implement further effective adaptation strategies.

Additionally there needs to be improvement in environmental and health monitoring and surveillance systems across Vanuatu. The health care sector could provide low cost monitoring mechanisms for specific vulnerable groups and hence sentinel data.

Although this project has identified many potential adaptation responses for Vanuatu, relatively little is known about the potential barriers to and opportunities for the introduction of the strategies and their cost effectiveness. Thus there is the need for more investigation/research into these issues. These processes also need to be linked with climate change activities by other organizations.

Recent increased awareness of changes in the climate and the potential impacts this may have on our health and way of life have resulted in an increased interest and concern about mitigation of adverse effects and implementation of adaptation measures to reduce adverse impacts. As more information becomes available from scientists and other specialists, it is clear that adaptation strategies need to be formulated for all sectors including health.

The extent of impacts from adverse effects will depend on how well society in Vanuatu can estimate the level of the impacts, the planning processes for adaptation strategies and the successful implementation of the adaptation measures. Concurrent with these processes will be measures to mitigate the changes in the various climatic parameters, which can result in environmental impacts.

It is accepted that climatic conditions in Vanuatu are changing and that physical and environmental changes will influence the way the community lives. This project has identified a number of potential health impacts that may arise from climate change in Vanuatu, and has considered a range of ways in which these could be managed. A number of potential adaptations that could be implemented across Vanuatu to avoid some of the more serious impacts of climate change on health have been identified and a model procedure which can be used, with some modification, to develop revised adaptation strategies as the predicted climate variables change and adaptation strategies has been introduced.

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References

- Australian Greenhouse Office. (2005). *Climate Change Impacts & Risk Management: A Guide for Business and Government*. Australian Government. Retrieved from <http://www.climatechange.gov.au/community/~medi a/publications/local-govt/risk-management.ashx>
- Brown, H. L., Prout, K., Spickett, J., & Capon, A. (2011). The potential role of Health Impact Assessment in tackling the complexity of climate change adaptation for health. *Health Promotion Journal of Australia*, 22, S48-S53.
- Commonwealth Scientific and Industrial Research Organisation. (CSIRO). (2006). *Climate change scenarios for*

- initial assessment of risk in accordance with risk management guidance. Australian Government. Retrieved from <http://ccsl.iccip.net/risk-scenarios.pdf>
- Campbell-Lendrum, D., & Woodruff, R. (2006). Comparative risk assessment of the burden of disease from climate change. *Env Health Perspect*, 114(12), 1935-1941.
- Fussell, H-M. (2008). Assessing adaptation to the health risks of climate change: what guidance can existing frameworks provide? *International Journal Environmental Health Research*, 18(1), 37-63. <http://dx.doi.org/10.1080/09603120701358416>
- Garnaut, R. (2008). The Garnaut Climate Change Review: Final Report. Cambridge University Press. Retrieved from <http://www.garnautreview.org.au>
- Indian Ocean Climate Initiative (IOCI). (2006). Report of Phase 2 Activity. Editors Ryan B. and Hope P. Retrieved from <http://www.ioci.org.au/pdf/IOCIRreport.pdf>
- Initial National Communication to the Conference of Parties to the United Nations Framework Convention on Climate Change. (1999). Retrieved from Government of Vanuatu.
- Intergovernmental Panel on Climate Change. (IPCC). (2007). Working Group II Fourth Assessment Report: Summary for Policymakers. Retrieved from <http://www.ipcc.ch/>
- Intergovernmental Panel on Climate Change. (IPCC). (2001). Working Group II: Impacts, Adaptation and Vulnerability. Retrieved from <http://www1.ipcc.ch/ipccreports/tar/wg2/006.htm>
- Ministry of Health Annual Report. (2010). Government of Vanuatu.
- National Adaptation Programme of Action. (2007). Government of Vanuatu.
- Nelson, D. (2003). Health impact assessment of climate change in Bangladesh. *Environmental Impact Assessment Review*, 23(3), 323-341.
- Pacific Climate Change Science Program. (PCCSP). (2011). Current and Future Climate of Vanuatu. Vanuatu Meteorology and Geo-Hazard Department, Australian Bureau of Meteorology and the Common wealth Scientific Industrial and Research Organisation. Retrieved from http://www.cawcr.gov.au/projects/PCCSP/pdf/15_PCCSP_Vanuatu_8pp.pdf
- Patz, J., Cambell-Lendrum, D., Gibbs, H., & Woodruff, R. (2008). Health impact assessment of global climate change: expanding on comparative risk assessment approaches for policy making. *Annu Rev Public Health*, 29, 27-39. <http://dx.doi.org/10.1146/annurev.publhealth.29.020907.090750>
- Spickett, J., Brown, H., & Katscherian, D. (2007). Health Impacts of climate change: Adaptation strategies for Western Australia. Department of Health, Government of Western Australia. Retrieved from <http://public.health.wa.gov.au>
- Standards Australia, Standards New Zealand. Risk Management. (2004). ASNZS: 4360. <http://www.saiglobal.com>
- World Health Organisation. (WHO). (2013a). Environmental health. Retrieved from http://www.who.int/topics/environmental_health/en/
- WHO. (2013b). Health impact assessment. <http://www.who.int/hia/evidence/doh/en/>
- WHO. (2009). Madang Commitment; 13-14. WHO and Secretariat for the Pacific Community.
- WHO. (2008). Framework for Action to Protect Human Health from the Effects of Climate Change in the Asia Pacific Region. WHO Western Pacific Regional Office, Manila.
- WHO. (2003a). Methods of assessing human health vulnerability and public health adaptation to climate change. Health and Global Environmental Change: Series 1. WHO Regional Office for Europe.
- WHO. (2003b). Climate change and human health – risks and responses. McMichael AJ, Campbell-Lendrum DH, Corvalan CF, Ebi KL et al. (Eds). WHO, WMO, UNEP. WHO, Geneva,
- WHO. (1999). Health Impact Assessment: Main Concepts and Suggested Approaches-the Gothenburg Consensus Paper. Brussels: European Centre for Health Policy, WHO Regional Office for Europe.
- WHO. (1990). Potential health effects of climatic change – report of a WHO Task Group. WHO, Geneva, WHO/PEP/90/10

Chapter Seven

Paper 4: Assessment of the health impacts of climate change in Kiribati

Prelude

The paper in this chapter describes a mixed-methods, “middle way” approach to climate change and health vulnerability assessment and adaptation planning in Kiribati - a densely populated, equatorial atoll country, considered to be one of the world’s most vulnerable to the impacts of climate change. This highly pragmatic approach, combining the utilisation of available data, consultation with relevant stakeholders and placement of a premium on contextual factors (particularly country limitations and policy priorities), could be justifiably considered the most appropriate option for small, resource-poor developing countries.

Kiribati has benefited, arguably to a greater extent than most other Pacific island countries, from consistently strong and outspoken leadership in relation to climate change. The country’s first president, Sir Ieremia Tabai, was early to recognise the severe challenges his small atoll nation faced with respect to rising seas and rapid population growth¹; his longest-serving successor, Anote Tong, has been one of the most prominent politicians on the global stage for over a decade advocating for action to arrest climate change.

This paper summarises the methods, results and lessons learned from the vulnerability assessment and adaptation planning project in Kiribati, and highlights the relevance of these findings for other small island developing states. It is reproduced here with the permission of MDPI, the publishers of the *International Journal of Environmental Research and Public Health*.

The candidate’s estimated proportional contributions to this paper were as follows:

Research design:	70%
Analysis and interpretation:	70%
Authorship of paper:	80%

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¹ New flags flying: Pacific leadership (2012). Johnstone I & Powles M, eds. Huia Publishers, Wellington, New Zealand

Article

Assessment of the Health Impacts of Climate Change in Kiribati

Lachlan McIver ^{1,2,*}, Alistair Woodward ³, Seren Davies ⁴, Tebikau Tibwe ⁴ and Steven Iddings ²

¹ Australian National University, Canberra, ACT 0200, Australia

² Division of Pacific Technical Support, World Health Organization, Suva, Fiji;
E-Mail: iddings@wpro.who.int

³ School of Population Health, Faculty of Medical and Health Sciences, University of Auckland, Auckland 1010, New Zealand; E-Mail: a.woodward@auckland.ac.nz

⁴ Ministry of Health and Medical Services, Bikenibau, Republic of Kiribati;
E-Mails: senyda@gmail.com (S.D.); tnoran@gmail.com (T.T.)

* Author to whom correspondence should be addressed; E-Mail: lachlan.mciver@gmail.com;
Tel./Fax: +61-3-9421-6754.

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Abstract: Kiribati—a low-lying, resource-poor Pacific atoll nation—is one of the most vulnerable countries in the World to the impacts of climate change, including the likely detrimental effects on human health. We describe the preparation of a climate change and health adaptation plan for Kiribati carried out by the World Health Organization and the Kiribati Ministry of Health and Medical Services, including an assessment of risks to health, sources of vulnerability and suggestions for highest priority adaptation responses. This paper identifies advantages and disadvantages in the process that was followed, lays out a future direction of climate change and health adaptation work in Kiribati, and proposes lessons that may be applicable to other small, developing island nations as they prepare for and adapt to the impacts of climate change on health.

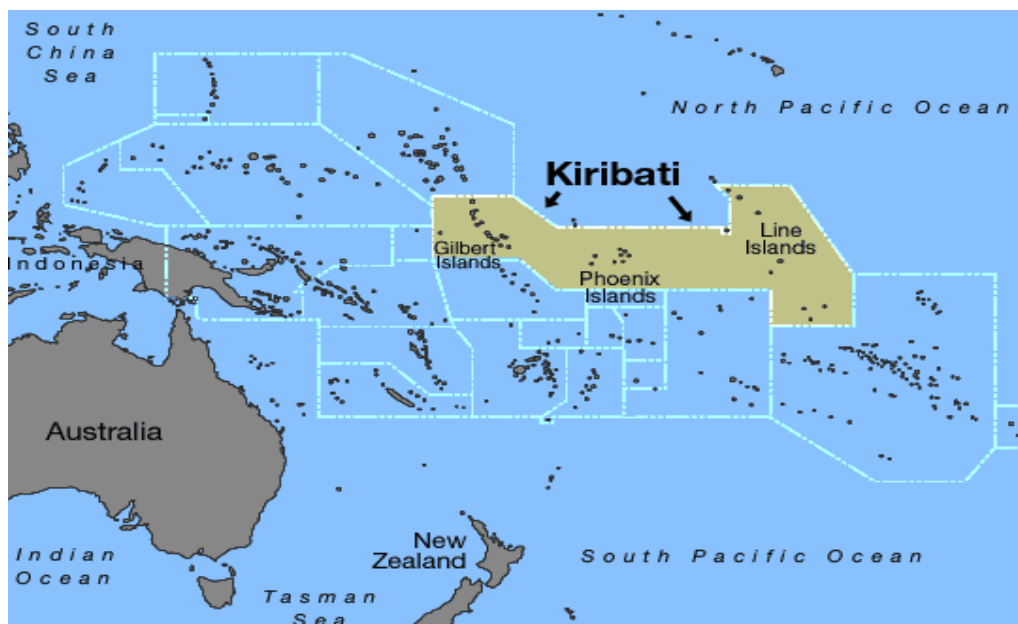
Keywords: climate change; health; adaptation; small island state

1. Introduction

1.1. Background to Climate Change in Kiribati

The Republic of Kiribati (Kiribati) is a low-lying country of thirty-three atolls, straddling the equator in the central Pacific (see Figure 1), with an average elevation of less than three metres above sea level. Roughly half of the total population of approximately 105,000 reside on the small atoll of South Tarawa (area 16 km²), with population densities approaching 10,000 persons per square kilometre in the most crowded parts of the atoll [1].

Figure 1. Map of Kiribati (source: Office of Te Beretitenti, Government of Kiribati).



The climate of Kiribati is hot and humid, with very little variation in maximum and minimum temperatures throughout the year. Droughts, usually associated with La Niña, can be very severe in Kiribati, such as the events that occurred in 1988–1989, 1998–1999, 2007–2009 and early 2011.

Kiribati is highly vulnerable to the impacts of climate change, due to, *inter alia*, limited land area and opportunities for domestic agriculture, over-crowding, the low elevation of the islands and the lack of safe and secure supplies of potable water. The particular threats posed by climate change for Kiribati include sea-level rise, increasing air and sea-surface temperatures, ocean acidification, altered rainfall patterns and the unpredictability of events such as droughts, storm surges and extreme high winds [2]. On short time scales, some of these changes can be seen already: ambient air temperatures (closely related to sea-surface temperatures in the case of Kiribati) have increased by approximately one degree Celsius since 1950 [2], and since 1992 sea-level around Kiribati has risen by 3.9 mm per year, three times faster than the global average [3].

1.2. Rationale for Assessment of Climate Change and Health in Kiribati

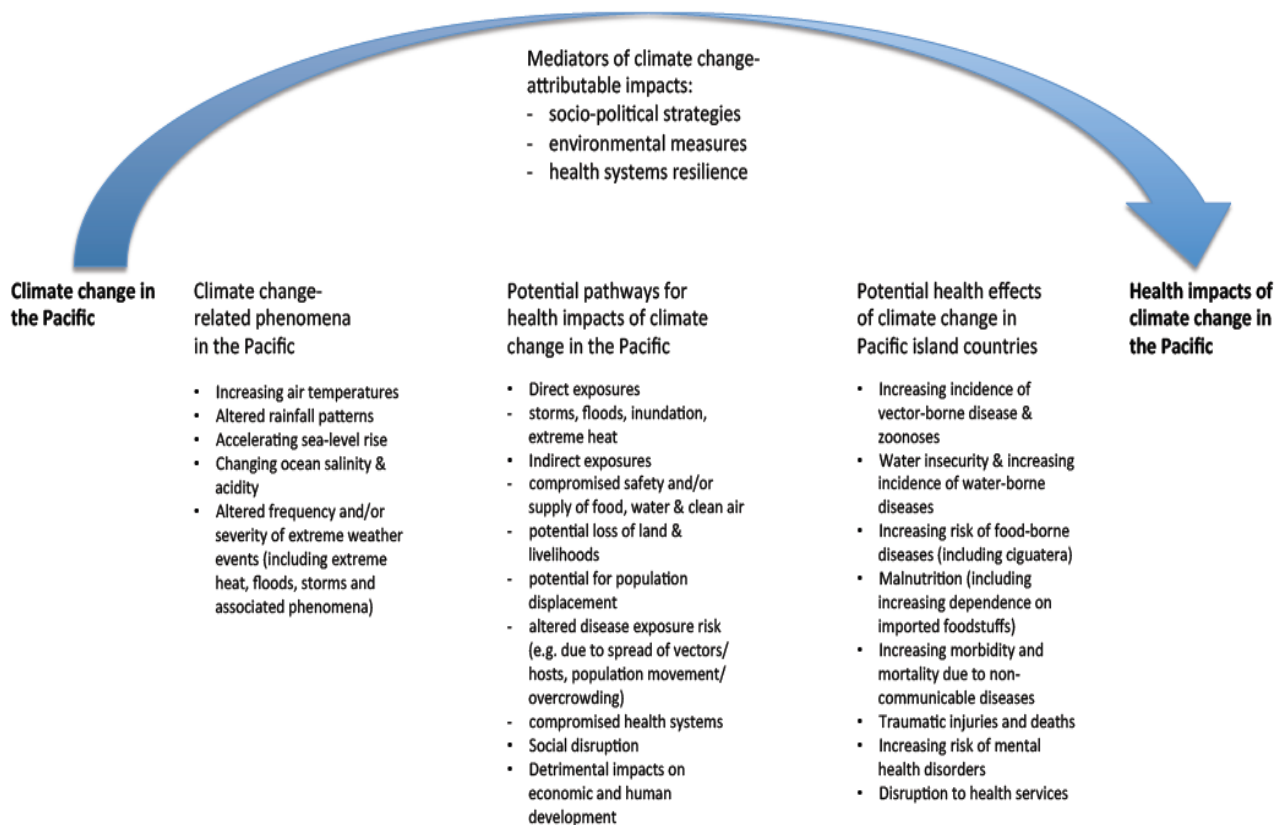
Climate change threatens not only the land and livelihoods of *i-Kiribati* communities, but also the health of the population. The pathways linking climate change to human health have been described

extensively in the literature [4–8]; however relatively little of this work to date has focussed on the South Pacific [9–13].

From 2010 to 2012, the World Health Organization (WHO) Division of Pacific Technical Support undertook a project supporting eleven Pacific island countries—including Kiribati—assess their vulnerability to climate change and compile national health adaptation strategies to manage those risks to health. The mandates for this project included the 2009 *Madang Commitment*, in which the Health Ministers of Pacific island countries committed to action on climate change [14]; and the 2008 WHO Regional Framework on climate change and health [15].

The main climate change-related health risks of concern in Pacific island countries, as identified in the WHO-supported vulnerability and adaptation assessment project, are summarised in Figure 2.

Figure 2. Overview of climate change and health vulnerabilities in Pacific island countries.



Recognising the vulnerability of the country to climate change, Kiribati was one of the first Pacific island states to prepare a National Adaptation Programme of Action (NAPA), prior to the commencement of the WHO-supported climate change and health project. Kiribati’s NAPA, finalised in 2007, made reference to several possible health impacts of climate change, including diarrhoeal disease, dengue fever, fish poisoning, social disruption and the health impacts of extreme weather events [16].

Following on from the NAPA, WHO and the Kiribati Ministry of Health and Medical Services (MHMS) undertook a more rigorous climate change and health vulnerability assessment. This led to the development of a National Climate Change and Health Action Plan (NCCHAP), as the health sector’s formal contribution to the cross-sectoral national adaptation planning process in Kiribati.

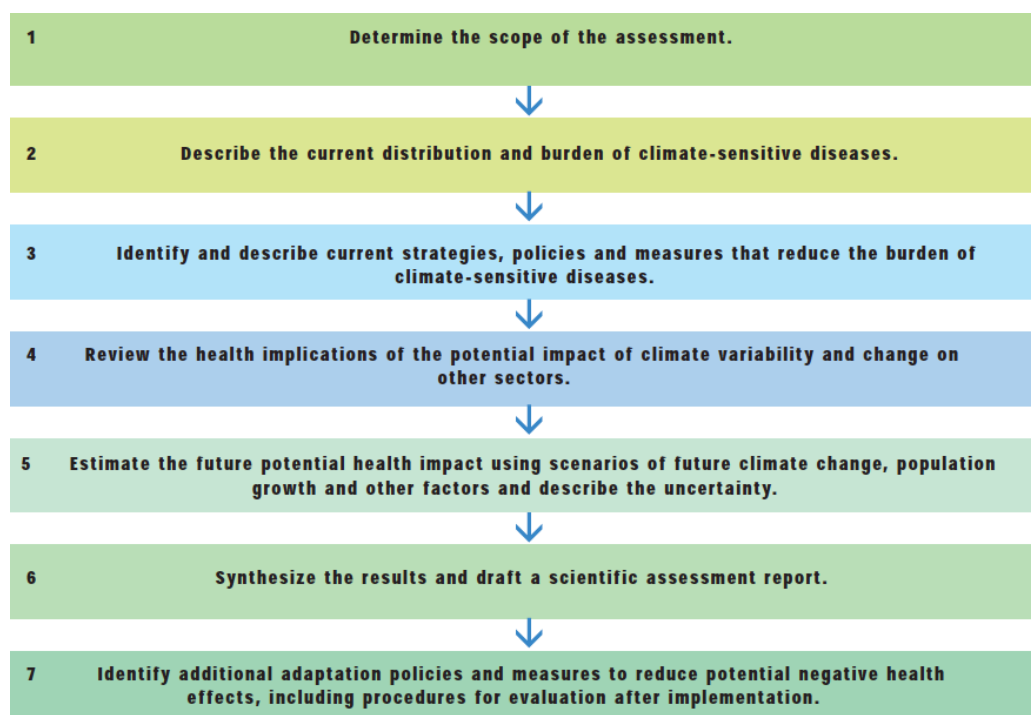
This paper describes the methods employed in Kiribati's climate change and health vulnerability assessment and adaptation planning, and summarises the outcomes.

It is important to note that the contemporary literature on health vulnerability and adaptation assessments includes descriptions of approaches to assessing climate change and health vulnerabilities, of both quantitative [17,18] and qualitative [19] varieties, but these methods do not always reflect the practical necessities of climate change and health work in small, developing countries, where resources are scant and the relevant data is scarce. We describe a “middle way” for climate change and health vulnerability and adaptation assessments, one that better fits, we suggest, the circumstances of small island developing states.

2. Methodology

The approaches that have been recommended for carrying out climate change and health vulnerability assessments and adaptation planning typically include a number of steps, from identifying the current burden of climate-sensitive diseases, to estimation of the future climate-change attributable burden of diseases, with consideration of strategies to minimize climate change-related risks to health and acknowledgement of the health impacts of adaptation in other sectors. The process employed in the vulnerability and adaptation assessment in Kiribati is detailed below, with reference to the guidelines provided in the literature [18,20] and summarized in Figure 3.

Figure 3. Steps in assessing vulnerability and adaptation (Source: Kovats *et al.*, 2003 [20]).



2.1. Determining the Scope of the Assessment

In Kiribati, the climate change and health vulnerability assessment began with a review of the available data on climate and climate-sensitive diseases, along with consideration of current public health capacity and adaptation activities. The WHO-MHMS team undertook a series of

consultations with stakeholders across departments of the MHMS, as well as other government agencies and non-government organizations (see Table 1), seeking views on the key problems posed by climate change, risks to health and priority adaptation strategies and activities for Kiribati.

The assessment began with an inception meeting (of representatives from Kiribati, Tuvalu, Niue, Tonga and the Cook Islands) in Auckland in 2010, and spanned four visits to Kiribati by WHO consultants and staff through 2011 and 2012.

Table 1. Matrix used to assess climate-sensitive health risks in Kiribati, in terms of their likelihood and impact.

Likelihood	Impact (Considering Consequence and Coping Capacity)				
	Insignificant	Minor	Moderate	Major	Catastrophic
Almost Certain	Medium	Medium	High	Extreme	Extreme
Likely	Low	Medium	High	High	Extreme
Possible	Low	Medium	Medium	High	High
Unlikely	Low	Low	Medium	Medium	Medium
Rare	Low	Low	Low	Low	Medium

2.2. Describing the Current Distribution and Burden of Climate-Sensitive Diseases

The WHO-MHMS team considered a long list of health issues in Kiribati that have the potential to be affected by changes in climate. In doing so, the team consulted with health stakeholders from a number of fields (environmental health, communicable diseases, NCDs, nutrition and mental health), including the relevant heads of departments within the MHMS. The list of potential climate-sensitive health risks generated for Kiribati included a number of communicable diseases (water-, food- and vector-borne diseases, infections of the eyes, skin and respiratory tract and zoonotic diseases), injuries, non-communicable diseases (NCDs) and heat-related illness, food security, malnutrition and mental health. Despite the lack of detailed information on disease rates, it was possible to identify the most pressing climate-sensitive health problems in Kiribati via consultation and review of the major causes of morbidity and mortality from routinely-collected MHMS data.

In order to prioritize adaptation strategies, in the absence of detailed information on risks and trends, the process in Kiribati relied to a significant extent on expert judgement. This approach employed estimates of the likelihood that climate change would exacerbate particular health risks, alongside the potential impact of these increased risks on the burden of disease. This “likelihood *versus* impact” model has proved useful in climate change and health impact assessments elsewhere in the Pacific [13] and is elaborated in Table 1. The core WHO-MHMS climate change and health team carried out this subjective analysis; on the advice of the MHMS stakeholders, the process was further simplified by splitting the climate-sensitive health risks into two categories only: “high risk” and “low risk” (see Results below).

2.3. Identifying and Describing Current Strategies, Policies and Measures that Reduce the Burden of Climate-Sensitive Diseases

To determine the priorities for this plan, the team focused on conditions that were strongly linked to changes in climate, that would add substantially to the burden of disease in Kiribati, and were

tractable—*i.e.*, where evidence was available on interventions that were likely to alleviate the current and future burdens of these diseases, for example water, sanitation and hygiene interventions for diarrhoeal illness [21]. While the MHMS had in place some routine policies and measures related to management of these risks—for example the National Water Resources and Sanitation Policies and the annual workplan of the MHMS Environmental Health Unit (EHU)—it was clear from the simple needs analysis conducted during the assessment process that substantial shortfalls in capacity and resources to manage these risks remained.

2.4. Reviewing the Health Implications of the Potential Impact of Climate Variability and Change on other Sectors

It was evident that, despite mention of health vulnerabilities in the NAPA, the current suite of adaptation plans and activities in Kiribati had not sufficiently taken into account the health implications of climate change. In particular, the marquee national adaptation program—the Kiribati Adaptation Plan (KAP), then approaching its third phase—was focused on infrastructure and coastal protection (e.g., construction of seawalls and planting of mangroves) without explicit consideration of the potential health impacts of these measures. Nor did the KAP grasp the opportunities—the health “co-benefits”—that might be achieved by emphasizing adaptation strategies closely aligned with health [22–24].

2.5. Estimating the Future Potential Health Impact Using Scenarios of Future Climate Change, Population Growth and other Factors, and Describing the Related Uncertainty

It was not feasible, given the lack of reliable historical health data and down-scaled climate projections, to calculate precisely the future climate-change attributable burdens of disease. However, on the basis of this assessment and the international literature, it was deemed highly likely that climate change would amplify current health risks. Of particular concern in Kiribati is the potential for climate change effects—particularly sea-level rise—to exacerbate overcrowding and add to the risk of infectious disease transmission [25].

2.6. Synthesizing the Results and Drafting a Scientific Assessment Report

The WHO-MHMS team compiled the aforementioned NCCHAP for Kiribati, which synthesized the process, outcomes and recommendations of the vulnerability and adaptation assessment. The most important elements of the plan are included in the Section Results. This NCCHAP has been used to inform funded adaptation project work related to water security and water-borne diseases in Kiribati (see Discussion for further details), and will be incorporated into a regional synthesis report on climate change and health in Pacific island countries, to be launched by WHO later this year.

2.7. Identifying Additional Adaptation Policies and Measures to Reduce Potential Negative Health Effects, Including Procedures for Evaluation Following Implementation

Procedures for review of priorities, implementation of plans and evaluation of processes articulated in the NCCHAP were incorporated into the recommendations. It will be a sign of success if future

assessments of climate change and health in Kiribati review the NCCHAP methodology, make changes where these are warranted, and update national plans accordingly.

Sources of information considered in the vulnerability assessment and adaptation planning process in Kiribati are summarized in Table 2 below.

Table 2. Information considered in the Kiribati climate change and health vulnerability assessment.

Type/Source of Information Reviewed and Consulted	Name/Description of Source and Information Obtained
Data	notifiable disease surveillance data from MHMS (Health Information Unit) annual reports from MHMS historical climate data from Kiribati Meteorology Service climate change data (historical trends and predictions) from Pacific Climate Change Science Program quality of household sanitation and water supplies, information obtained from the 2010 national census population data (2010 census)
Stakeholders	Office of Te Beretitenti (Office of the President) Ministry of Health and Medical Services Ministry of Public Works and Utilities Ministry of Internal and Social Affairs Ministry of Fisheries and Marine Resources Development Ministry of Environment, Lands and Agricultural Development Ministry of Commerce, Industries and Cooperatives Kiribati Port Authority Overseas Environmental Cooperation Centre Secretariat for the Pacific Community (including the South Pacific Applied Geosciences Commission) Kiribati Association of Non-Government Organizations Community members (during health promotion workshops) World Health Organization
Previous/current activities related to climate change adaptation	National Adaptation Programme of Action (NAPA) Kiribati Adaptations Plans (I-III) Climate Change Adaptation Plan and Strategy National Framework for Climate Change Adaptation Second National Communication (to the United Nations Framework Convention on Climate Change) Kiribati Development Plan Kiribati National Development Strategies
Previous/current activities related to public health	Ministry of Health and Medical Services' Strategic Plan National Population Policy National Disaster Risk Management Plan National Sanitation Implementation Plan

3. Results

In determining the priorities for the Kiribati NCCHAP, the WHO-MHMS team focused on conditions that:

- (a) have been shown to be strongly linked to changes in climate (based on empirical epidemiological evidence and expert judgement);
- (b) would likely add substantially to the burden of disease in Kiribati; and
- (c) could be reduced by feasible public and environmental health interventions.

The list of climate-sensitive health risks considered in the final NCCHAP for Kiribati includes is shown in Table 3. In this Table, “low priority” does not necessarily mean unimportant, but rather that the issue in question is considered to be of a relatively lower priority than those deemed to be “high”. Note also the inclusion of disease surveillance, which is clearly not a health condition, but a health-protective measure—this was included because the team judged that surveillance would be central to managing most climate-related risks to health in Kiribati.

Table 3. Climate change and health adaptation priorities in Kiribati.

Health Issue Likely to be Affected by Climate Change	Priority
Water safety and water-borne diseases	High
Food safety and food-borne diseases	High
Vector-borne diseases	High
Disease surveillance	High
Respiratory diseases	Low
Malnutrition	Low
Non-communicable diseases and heat-related illness	Low
Ciguatera	Low
Mental health	Low
Reproductive health	Low

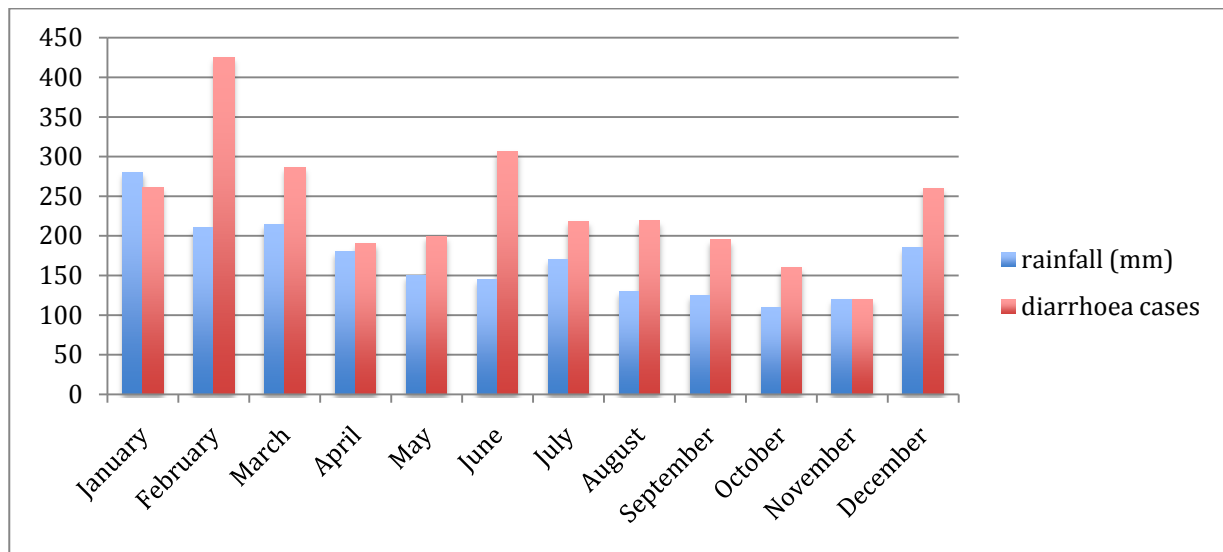
The priority areas for climate change and health adaptation in Kiribati identified in this project and listed in Table 3 all meet the abovementioned three criteria of being linked to climate change; likely to exacerbate existing burdens of diseases; and amenable to public and/or environmental health intervention.

3.1. Water Safety and Water-borne Diseases

As an atoll country, Kiribati’s potable water is drawn exclusively from aquifers and harvested rainwater. According to a 2011 report compiled by the United Nations Office for the Coordination of Humanitarian Affairs, in collaboration with UNICEF and the Secretariat for the Pacific Community (SPC), distribution, contamination of the aquifers and other effects of population growth and increasing density of settlement all pose challenges to water quality in Kiribati. The same report describes the risks to health and livelihoods posed by drought. Extremes of rainfall are correlated with the incidence of water-borne diseases (such as diarrhoeal disease, cholera and typhoid fever) in the Pacific region [11] and elsewhere [26–30]. In South Tarawa, on the basis of the scant data available, there appeared to be at least a modest seasonal pattern of diarrhoeal disease incidence, with the number

of monthly cases of diarrhoea in the heavily populated area of Betio rising with the onset of heavy rains in December in recent years (Figure 4).

Figure 4. Average monthly rainfall (Kiribati), and reported cases of diarrhoea (all ages) in Betio district, South Tarawa, 2009–2010.



Community stakeholders pointed out that end-of-year cultural gatherings of large groups may contribute to an increase in food-borne infections causing diarrhoea, but it is also plausible that run-off following heavy rains and contamination of drinking water sources contributes to this problem. Projections for future climates in Kiribati generally indicate an increase in the days of very heavy rainfall by 2050 [2], raising the possibility of an increased risk of water-borne diseases in heavily contaminated, crowded areas, unless measures are taken to protect water supplies and block the transmission of infections. Cost-effective interventions may include hand-washing, household water treatment and the implementation of water safety plans [31–33], ideally in combination with larger-scale improvements to water safety testing and infrastructure where there is a clear need (as there is in Kiribati).

3.2. Food Safety and Food-borne Diseases

As an equatorial country which experiences consistently high ambient temperatures and high humidity, with limited facilities for refrigeration and secure food storage, Kiribati is at high risk of illnesses due to contamination of food by bacteria, viruses and toxins. These illnesses may be exacerbated by climate change [34–36], but there are opportunities also to reduce risks by improvements in storage, food preparation and handling.

3.3. Vector-borne Diseases

Many vector-borne diseases, including those affecting the population of Kiribati (e.g., dengue fever and lymphatic filariasis) are sensitive to changes in climate variables such as temperature, rainfall and humidity [37–40], and therefore may be influenced by climate change [41]. Kiribati has experienced at least three major epidemics of dengue fever since 2003. There is a competent vector present in the form of the *Aedes aegypti* mosquito, the atolls provide an abundance of breeding sites (including tyres,

cans, bottles, shells and coconut husks) and there are high densities of potential human hosts in certain dengue fever “hotspots” on South Tarawa. Improved disease surveillance (e.g., implementation of a syndromic surveillance approach) and mosquito control programs have reduced the frequency and intensity of dengue fever outbreaks in other developing countries [42].

3.4. Disease Surveillance

Expanded or enhanced surveillance for climate-sensitive communicable diseases is one of the most frequently-cited examples of climate change adaptation in the health context [43], particularly with respect to climate-based epidemic early warning systems for climate-sensitive diseases such as those listed above [44–46].

3.5. Respiratory Diseases

Respiratory diseases—including those with infectious causes (e.g., pneumonia, viruses) and other aetiologies such as asthma—have been linked with climate variability and change [47,48]. It is relevant to note that Kiribati has very high rates of smoking and overcrowding, which are additional risk factors for transmission of respiratory infections, but are also obvious areas for action in the adaptation context.

3.6. Malnutrition

I-Kiribati communities, particularly children, are already at significant risk of malnutrition due to the lack of suitable land for agriculture and the country’s increasing dependence on energy-dense, imported foodstuffs. The concern is that climate change will exacerbate this risk via its detrimental effects on crops and fisheries, increasing the incidence of childhood diseases such as diarrhoea (for which malnutrition is a risk factor) and decreasing individuals’ willingness and ability to perform outdoor work or exercise in higher temperatures [5,49]. Much work and investment will be needed to secure suitable nutrition for Kiribati’s population as part of adaptation in the face of climate change. One example is the current attempt to breed drought- and salt-resistant crops such as taro and cassava—staple foods in Kiribati and across the Pacific.

3.7. Non-communicable Diseases and Heat-related illnesses

Climate change may have far-reaching impacts on non-communicable diseases (such as diabetes and circulatory disease), via complex and as yet poorly understood pathways [50,51]. As a poor, developing nation that already experiences high levels of cardiovascular diseases, cancer and diabetes, Kiribati is unfortunately situated to experience the additional driving force of climate change on non-communicable diseases. Increasing ambient temperatures are likely to increase hospitalizations and deaths of individuals with cardiovascular and respiratory illnesses, as has been demonstrated in other parts of the world, including tropical regions [52,53].

3.8. Ciguatera

Ciguatera (a toxidrome caused by ingestion of a dinoflagellate organism which bio-accumulates in the marine food chain) has been linked with sea-surface temperatures and thus with climate change in the Pacific, albeit with somewhat conflicting results [54–56]. Kiribati has among the highest reported rates of “fish poisoning” (noting that this does not necessarily or always imply ciguatera) in the Pacific, and local studies by the Ministry of Fisheries and Marine Resources Development suggest that the number and range of ciguatoxic fish may be expanding in reef areas around Kiribati.

3.9. Mental Health

Climate change may threaten the mental health of *i-Kiribati* communities as rising seas erode land and livelihoods, threatening the country’s sovereignty and national identity. Unfortunately, there is relatively little published in the scientific literature on the mental health impacts of climate change outside the northern hemisphere and developed southern hemisphere countries such as Australia [57–59], although some inferences may be made from the evidence on the mental health consequences of natural disasters [59–61]. In addition, in Kiribati very little is known about the present burden of mental ill-health, so it is challenging to identify with confidence the characteristics of these problems and the groups in the community that are, or will be, most affected.

3.10. Reproductive Health

One of the major demographic, health, social and development challenges for Kiribati is how to respond to the country’s rapid population growth. High fertility rates (estimated from the 2010 census as 3.8 children per woman), increasing population density in Tarawa, and decreasing habitable land area due to sea-level rise and coastal inundation have already forced the Government of Kiribati to prioritize population control and resettlement (including policies on emigration) in its National Framework for Climate Change Adaptation. While it may be considered by many to be a reasonably effective adaptation strategy, climate change-induced migration itself is likely to have profound health consequences on both source and recipient communities [62].

3.11. Vulnerable Groups

It is well established in the climate change and health literature that certain groups are likely to be disproportionately affected by climate change. Such sub-populations include the very young, the elderly, those with disabilities and pre-existing medical conditions, people residing in highly vulnerable areas (which may be considered to include the entire population of Kiribati, given the unique geographic susceptibilities inherent in the width and elevation of exclusively-atoll countries in the context of climate change) and those in certain occupations (fishers, farmers, construction and other outdoor workers) [53].

4. Discussion

4.1. Innovations and Challenges in the Vulnerability Assessment and Adaptation Planning Process in Kiribati

The climate change and health vulnerability and adaptation assessment in Kiribati combined quantitative elements—utilizing disease surveillance and climate data where possible, to give an indication of climate and climate-sensitive disease trends—with a strong qualitative element, largely carried out via engagement with stakeholders from the MHMS, other government agencies, community representatives and the Kiribati Association of NGOs (KANGO). This mixed-methods approach utilized the key features from published guidelines such as those described in the Section Methodology above, in synergy with a pragmatic, “no regrets” approach—defined as that which “increases the capacity of society to manage climate risks with a view to reduce the vulnerability of households and maintain or increase the opportunities for sustainable development” [63]—which has been recommended for smaller and/or developing countries and weaker health systems [64]. This process also incorporated elements from the Health Impact Assessment (HIA) literature, which has been adapted to the climate change and health context [19,65,66], particularly with respect to the health adaptation opportunities in non-health sectors (e.g., agriculture, energy, transport and infrastructure) and across the governance spectrum (e.g., from regulation and legislation to ecosystem intervention, research, technological innovation and infrastructure development).

The process of prioritizing climate change-related risks to health in Kiribati was hampered by the lack of reliable long-term data on disease incidence and health care utilization. Given the data paucity, priority risks and adaptation strategies were arrived at in large part by a process of consensus building and “expert opinion”, which has obvious limitations [67].

Nevertheless, the authors believe that a mixed-methods approach to climate change and health vulnerability and adaptation assessment, such as that described herein for Kiribati—grounded in theory but flexible in the face of on-the-ground realities and data and resource constraints—is likely to prove the approach most suitable for small island developing states and many least developed countries in the foreseeable future.

4.2. Future Direction of Climate Change and Health Adaptation in Kiribati

The key recommendations contained within the Kiribati NCCHAP reflect the priorities listed above, and relate primarily to strengthening climate-sensitive disease surveillance; improving resourcing for the MHMS EHU (particularly for those activities related to water safety, food safety and vector control); increasing the data quality and analytical capacity of the MHMS Health Information Unit; securing the necessary technical and financial support for community and health sector adaptation; and ensuring appropriate policy development in the field of climate change and health—for example, using the NCCHAP as the health sector’s contribution towards ongoing national adaptation planning in Kiribati.

It is hoped that health adaptation to climate change in Kiribati will be guided by the NCCHAP, but it is also anticipated that this vulnerability and assessment process is merely a starting point, which must be revised and updated regularly to incorporate new information, science and evidence, and to reflect current activities and shifting priorities related to public health in Kiribati.

Early signs of progress in implementing the NCCHAP are evident in a European Union-funded project, housed within the MHMS EHU, directed by the Secretariat for the Pacific Community and based on the NCCHAP, which prioritises water safety and water-borne diseases and aims to strengthen the capacity of the EHU with regards to its activities and resources as a critical aspect of adaptation in Kiribati.

5. Conclusions

This paper describes a “middle way” for climate change and health vulnerability assessment and adaptation planning in a low-lying small island developing state. This approach, which combines both quantitative and qualitative elements and has as its foundation the empirical framework for climate change and health assessments drawn from the international literature, but that also relies upon a pragmatic and consensual process to ensure relevance and feasibility with respect to adaptation plans and implementation thereof, may be the optimal strategy for other, comparable developing and/or island countries. There are a number of features of climate change and health risk and adaptation planning described in this paper which are not unique to Kiribati; other Pacific atoll countries such as Tuvalu, the Marshall Islands and Tokelau may benefit particularly from utilization of the approach outlined in this paper and the lessons learned from Kiribati’s experience in finalizing and implementing its NCCHAP.

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Author Contributions

Steven Iddings designed the original project. Alistair Woodward, Lachlan McIver, Seren Davies and Tebikau Tibwe carried out the work in Kiribati, for which Alistair Woodward was the consultant team leader for WHO and Lachlan McIver the WHO project officer, while Seren Davies and Tebikau Tibwe were the responsible officers for MHMS at different stages of the project. Lachlan McIver led the drafting of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. *Ministry of Finance and Economic Planning 2010; Census of Population and Housing, National Statistics Office: Bairiki, Tarawa, Republic of Kiribati, 2012.*

2. *Climate Change in the Pacific: Scientific Assessment and New Research—Country Report for Kiribati*; Pacific Climate Change Science Program, Australian Bureau of Meteorology and the Commonwealth Scientific Industrial and Research Organisation: Canberra, Australia, 2011.
3. Aung, T.; Singh, A.; Prasad, A. A study of sea-level changes in the Kiribati area for the last 16 years. *Weather* **2009**, *64*, 203–206.
4. McMichael, T.; Montgomery, H.; Costello, A. Health risks, present and future, from global climate change. *BMJ* **2012**, *344*, doi:10.1136/bmj.e1359.
5. Haines, A.; Kovats, R.S.; Campbell-Lendrum, D.; Corvalan, C. Climate change and human health: Impacts, vulnerability and public health. *Public Health* **2006**, *120*, 585–596.
6. Singh, S.; Mushtaq, U.; Holm-Hansen, C.; Milan, D.; Cheung, A.; Watts, N. The importance of climate change to health. *Lancet* **2011**, *378*, 29–30.
7. Patz, J.A.; Campbell-Lendrum, D.; Holloway, T.; Foley, J.A. Impact of regional climate change on human health. *Nature* **2005**, *438*, 310–317.
8. Kovats, R.S.; Menne, B.; McMichael, A.J.; Corvalan, C.; Bertollini, R. *Climate Change and Human Health: Impact and Adaptation*; WHO: Geneva, Switzerland, 2000.
9. Woodward, A.; Hales, S.; Weinstein, P. Climate change and human health in the Asia Pacific region: Who will be most vulnerable? *Clim. Res.* **1998**, *11*, 31–38.
10. Lovell, S.A. Health governance and the impact of climate change on Pacific small island developing states. *IHDP Update* **2011**, *1*, 50–55.
11. Singh, R.B.; Hales, S.; de Wet, N.; Raj, R.; Hearnden, M.; Weinstein, P. The influence of climate variation and change on diarrheal disease in the Pacific Islands. *Environ. Health Perspect.* **2001**, *109*, 155–159.
12. Ebi, K.L.; Lewis, N.D.; Corvalan, C.; Lucia, S. Climate variability and change and their potential health effects in small island states: Information for adaptation planning in the health sector. *Environ. Health Perspect.* **2006**, *114*, 1957–1963.
13. Spickett, J.T.; Katscherian, D.; McIver, L. Health impacts of climate change in Vanuatu: An assessment and adaptation action plan. *Glob. J. Health Sci.* **2013**, *5*, 42–53.
14. *WHO and Secretariat for the Pacific Community Madang Commitment*; WHO and Secretariat for the Pacific Community: Geneva, Switzerland, 2009; pp. 13–14.
15. *Regional Framework for Action to Protect Human Health from Effects of Climate Change in the Asia-Pacific Region*; World Health Organization, Western Pacific Regional Office: Manila, Philippines, 2007; pp. 1–4.
16. *National Adaptation Programme of Action (NAPA)*; Ministry of Environment, Land and Agricultural Development: Tarawa, Republic of Kiribati, 2007.
17. Campbell-Lendrum, D.; Woodruff, R. Climate Change: Quantifying the Health Impact at National and Local Levels. 2007. Available online: http://whqlibdoc.who.int/publications/2007/9789241595674_eng.pdf?ua=1 (accessed on 7 May 2014).
18. Ebi, K.L.; Kovats, R.S.; Menne, B. An approach for assessing human health vulnerability and public health interventions to adapt to climate change. *Environ. Health Perspect.* **2006**, *114*, 1930–1934.

19. Spickett, J.T.; Brown, H.L.; Katscherian, D. Adaptation strategies for health impacts of climate change in Western Australia: Application of a health impact assessment framework. *Environ. Impact Assess. Rev.* **2011**, *31*, 297–300.
20. Kovats, S.; Ebi, K.; Menne, B. Methods of Assessing Human Health Vulnerability and Public Health Adaptation to Climate Change. Available online: http://www.euro.who.int/__data/assets/pdf_file/0009/91098/E81923.pdf (accessed on 7 May 2014).
21. Prüss-Ustün, A.; Corvalán, C. How much disease burden can be prevented by environmental interventions? *Epidemiology* **2007**, *18*, 167–178.
22. Bank, World. *Kiribati Adaptation Program—Phase III Project Appraisal Document*; East Asia and Pacific Region, World Bank Sustainable Development: Washington DC, USA, 2011.
23. Cheng, J.J.; Berry, P. Health co-benefits and risks of public health adaptation strategies to climate change: A review of current literature. *Int. J. Public Health* **2013**, *58*, 305–311.
24. Ganten, D.; Haines, A.; Souhami, R. Health co-benefits of policies to tackle climate change. *Lancet* **2010**, *376*, 1802–1804.
25. Parker, C.L. Health impacts of sea-level rise. *Plan. Environ. Law* **2014**, *66*, 8–12.
26. Hashizume, M.; Armstrong, B.; Hajat, S.; Wagatsuma, Y.; Faruque, A.S.G.; Hayashi, T.; Sack, D.A. Association between climate variability and hospital visits for non-cholera diarrhoea in Bangladesh: Effects and vulnerable groups. *Int. J. Epidemiol.* **2007**, *36*, 1030–1037.
27. Milojevic, A.; Armstrong, B.; Hashizume, M.; McAllister, K.; Faruque, A.; Yunus, M.; Streatfield, P.K.; Moji, K.; Wilkinson, P. Health effects of flooding in rural Bangladesh. *Epidemiology* **2012**, *23*, 107–115.
28. Funari, E.; Manganelli, M.; Sinisi, L. Impact of climate change on waterborne diseases. *Ann. Ist. Super. Sanita* **2012**, *48*, 473–487.
29. Cann, K.F.; Thomas, D.R.; Salmon, R.L.; Wyn-Jones, A.P.; Kay, D. Extreme water-related weather events and waterborne disease. *Epidemiol. Infect.* **2013**, *141*, 671–686.
30. Spini, L.; Adeel, Z.; Rosenberg, M.W. The nexus of water and human health in the context of global changes. *Curr. Opin. Environ. Sustain.* **2011**, *3*, doi:10.1016/j.cosust.2011.11.001.
31. Fewtrell, L.; Kaufmann, R.; Kay, D. Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: A systematic review and meta-analysis. *Lancet Infect.* **2005**, *5*, 42–52.
32. Gunnarsdottir, M.J.; Gardarsson, S.M.; Elliott, M.; Sigmundsdottir, G.; Bartram, J. Benefits of water safety plans: Microbiology, compliance, and public health. *Environ. Sci. Technol.* **2012**, *46*, 7782–7789.
33. Markandya, A.; Chiabai, A. Valuing climate change impacts on human health: Empirical evidence from the literature. *Int. J. Environ. Res. Public Health* **2009**, *6*, 759–786.
34. El-Fadel, M.; Ghanimeh, S.; Maroun, R.; Alameddine, I. Climate change and temperature rise: Implications on food- and water-borne diseases. *Sci. Total Environ.* **2012**, *437*, 15–21.
35. Semenza, J.C.; Suk, J.E.; Estevez, V.; Ebi, K.L.; Lindgren, E. Mapping climate change vulnerabilities to infectious diseases in Europe. *Environ. Health Perspect.* **2012**, *120*, 385–392.
36. Rose, J.B.; Epstein, P.R.; Lipp, E.K.; Sherman, B.H.; Bernard, S.M.; Patz, J.A. Climate variability and change in the United States: Potential impacts on water- and foodborne diseases caused by microbiologic agents. *Environ. Health Perspect.* **2001**, *109*, 211–221.

37. Chowell, G.; Cazelles, B.; Broutin, H.; Munayco, C.V. The influence of geographic and climate factors on the timing of dengue epidemics in Perú, 1994–2008. *BMC Infect. Dis.* **2011**, *11*, doi:10.1186/1471-2334-11-164.
38. Thai, K.T.D.; Anders, K.L. The role of climate variability and change in the transmission dynamics and geographic distribution of dengue. *Exp. Biol. Med.* **2011**, *236*, 944–954.
39. Rosa-Freitas, M.G.; Schreiber, K.V.; Tsouris, P.; Weimann, E.T.D.S.; Luitgards-Moura, J.F. Associations between dengue and combinations of weather factors in a city in the Brazilian Amazon. *Rev. Panam. Salud Publica* **2006**, *20*, 256–267.
40. Hunter, P.R. Climate change and waterborne and vector-borne disease. *J. Appl. Microbiol.* **2003**, *94*, S37–S46.
41. Hales, S.; de Wet, N.; Maindonald, J.; Woodward, A. Potential effect of population and climate changes on global distribution of dengue fever: An empirical model. *Lancet* **2002**, *360*, 830–834.
42. Guzman, M.G.; Halstead, S.B.; Artsob, H.; Buchy, P.; Farrar, J.; Gubler, D.J.; Hunsperger, E.; Kroeger, A.; Margolis, H.S.; Martínez, E.; *et al.* Dengue: A continuing global threat. *Nat. Rev. Microbiol.* **2010**, *8*, S7–S16.
43. Weiss, R.A.; McMichael, A.J. Social and environmental risk factors in the emergence of infectious diseases. *Nat. Med.* **2004**, *10*, S70–S76.
44. Lowe, R.; Bailey, T.C.; Stephenson, D.B.; Jupp, T.E.; Graham, R.J.; Barcellos, C.; Carvalho, M.S. The development of an early warning system for climate-sensitive disease risk with a focus on dengue epidemics in southeast Brazil. *Stat. Med.* **2013**, *32*, 864–883.
45. Chaves, L.F.; Pascual, M. Comparing models for early warning systems of neglected tropical diseases. *PLoS Negl. Trop. Dis.* **2007**, *1*, doi:10.1371/journal.pntd.0000033.
46. Yu, H.-L.; Yang, S.J.; Yen, H.J.; Christakos, G. A spatio-temporal climate-based model of early dengue fever warning in southern Taiwan. *Environ. Res.* **2011**, *25*, 485–494.
47. Paynter, S.; Ware, R.S.; Weinstein, P.; Williams, G.; Sly, P.D. Childhood pneumonia: A neglected, climate-sensitive disease? *Lancet* **2010**, *376*, 1804–1805.
48. Takaro, T. Climate change and respiratory health: Current evidence and knowledge gaps. *Expert Rev. Resp. Med.* **2013**, *7*, 349–361.
49. Ebi, K.L. Adaptation costs for climate change-related cases of diarrhoeal disease, malnutrition, and malaria in 2030. *Global Health* **2008**, *4*, doi:10.1186/1744-8603-4-9.
50. Friel, S.; Bowen, K.; Campbell-Lendrum, D.; Frumkin, H.; McMichael, A.J.; Rasanathan, K. Climate change, noncommunicable diseases, and development: The relationships and common policy opportunities. *Annu. Rev. Public Health* **2011**, *32*, 133–147.
51. Kjellstrom, T.; McMichael, A.J. Climate change threats to population health and well-being: The imperative of protective solutions that will last. *Glob. Health Action* **2013**, *6*, 1–9.
52. Tawatsupa, B.; Dear, K.; Kjellstrom, T.; Sleigh, A. The association between temperature and mortality in tropical middle income Thailand from 1999 to 2008. *Int. J. Biometeorol.* **2014**, *58*, 203–215.
53. Lundgren, K.; Kuklane, K.; Gao, C.; Holmér, I. Effects of heat stress on working populations when facing climate change. *Ind. Health* **2013**, *51*, 3–15.
54. Hales, S.; Weinstein, P.; Woodward, A. Ciguatera (fish poisoning), El Niño, and Pacific Sea surface temperatures. *Ecosyst. Health* **1999**, *5*, 20–25.

55. Skinner, M.P.; Brewer, T.D.; Johnstone, R.; Fleming, L.E.; Lewis, R.J. Ciguatera fish poisoning in the Pacific Islands (1998 to 2008). *Methods* **2011**, *5*, 1–7.
56. Llewellyn, L.E. Revisiting the association between sea surface temperature and the epidemiology of fish poisoning in the South Pacific: Reassessing the link between ciguatera and climate change. *Toxicon* **2010**, *56*, 691–697.
57. Berry, H.L.; Bowen, K.; Kjellstrom, T. Climate change and mental health: A causal pathways framework. *Int. J. Public Health* **2010**, *55*, 123–132.
58. Albrecht, G.; Sartore, G.; Connor, L.; Higginbotham, N.; Freeman, S.; Kelly, B.; Stain, H.; Tonna, A.; Pollard, G. Solastalgia: The distress caused by environmental change. **2007**, *15*, 95–98.
59. Davidson, J.R.; McFarlane, A.C. The extent and impact of mental health problems after disaster. *J. Clin. Psychiat.* **2006**, *67*, 9–14.
60. Berry, H.; Bowen, K.; Kjellstrom, T. Climate change and mental health—A causal pathways framework. *Int. J. Public Health* **2010**, *55*, 123–132.
61. O'Brien, L.V.; Berry, H.L.; Coleman, C.; Hanigan, I.C. Drought as a mental health exposure. *Environ. Res.* **2014**, *131*, 181–187.
62. McMichael, C.; Barnett, J.; McMichael, A.J. An ill wind? Climate change, migration, and health. *Environ. Health Perspect.* **2012**, *120*, 646–654.
63. Heltberg, R.; Siegel, P.B.; Jorgensen, S.L. Addressing human vulnerability to climate change: Toward a “no-regrets” approach. *Glob. Environ. Chang.* **2009**, *19*, 89–99.
64. Wardekker, J.A.; de Jong, A.; van Bree, L.; Turkenburg, W.C.; van der Sluijs, J.P. Health risks of climate change: An assessment of uncertainties and its implications for adaptation policies. *Environ. Health* **2012**, *11*, doi:10.1186/1476-069X-11-67.
65. Patz, J.; Campbell-Lendrum, D.; Gibbs, H.; Woodruff, R. Health impact assessment of global climate change: Expanding on comparative risk assessment approaches for policy making. *Annu. Rev. Public Health* **2008**, *29*, 27–39.
66. Chalabi, Z.; Kovats, S. Tools for developing adaptation policy to protect human health. *Mitig. Adapt. Strateg. Glob. Change* **2014**, *19*, 309–330.
67. Randolph, S.E. Is expert opinion enough? A critical assessment of the evidence for potential impacts of climate change on tick-borne diseases. *Anim. Health Res. Rev.* **2013**, *14*, 133–137.

Chapter Eight

Paper 5: Climate change and health in Fiji:
environmental epidemiology of infectious diseases and
potential for climate-based early warning systems

Prelude

This paper is the first in a two-part series published in the *Fiji Journal of Public Health* to describe Fiji's "Piloting Climate Change Adaptation to Protect Human Health" (PCCAPHH) project. This initiative was Fiji's contribution to a seven-country global climate change and health pilot project, led by WHO with support from the United Nations Development Programme (UNDP) and funding from the GEF.

The project team in Fiji, under the guidance of the national steering committee (chaired by the Permanent Secretary of the Ministry of Health), elected to focus its national vulnerability assessment on four high-priority climate-sensitive diseases: dengue fever, diarrhoeal disease, leptospirosis and typhoid fever; collectively known as the "Four Plagues" of Fiji.

The first half of this paper describes the process of analysing these diseases at a national and provincial level with respect to their clustering in space and time, and their correlation with meteorological variables such as temperature, rainfall and humidity, as well as their association with extreme events such as droughts, floods and cyclones – all unfortunately common occurrences in Fiji.

The second half of the paper considers the possibility of using such analytical techniques to inform climate-based early warning systems to alert policy-makers and public health practitioners to the possibility of epidemics of these diseases.

The candidate's estimated proportional contributions to this paper were as follows:

Research design:	60%
Analysis and interpretation:	60%
Authorship of paper:	90%

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Reference: Mclver L, Naicker J, Hales S, Singh S, Dawainavesi A. Climate change and health in Fiji: environmental epidemiology of infectious diseases and potential for climate-based early warning systems. *Fiji Journal of Public Health* 2012; 1(1): 7-13

CLIMATE CHANGE AND HEALTH IN FIJI: ENVIRONMENTAL EPIDEMIOLOGY OF INFECTIOUS DISEASES AND POTENTIAL FOR CLIMATE-BASED EARLY WARNING SYSTEMS

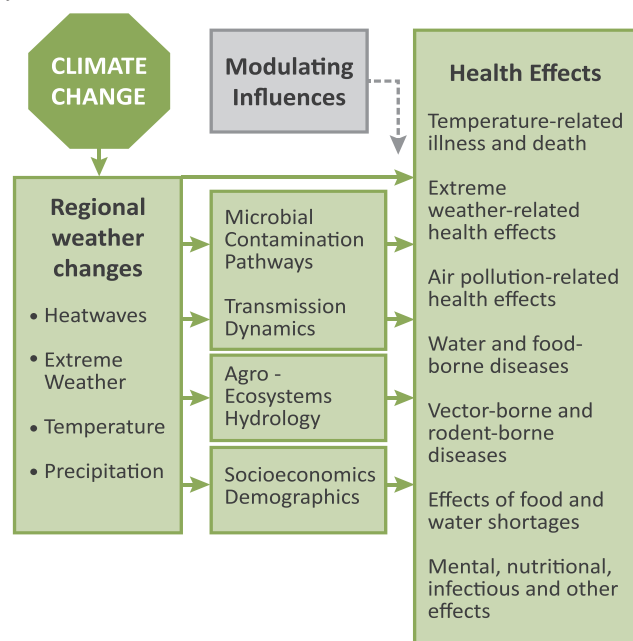
McIver LJ^{1,2,*}, Naicker J^{1,2}, Hales S³, Singh S¹ and Dawainavesi A^{1,2}

Keywords: climate change, climate-sensitive disease, early warning system

INTRODUCTION

The health impacts of climate change are cause for growing public health concern around the world. Anthropogenic (human-induced) changes in the physical environment due to global greenhouse gas emissions include rising air and sea-surface temperatures, altered rainfall patterns and rising sea levels; these phenomena are linked to health outcomes via a number of complex, direct and indirect pathways (see *Figure 1*). While *Figure 1* demonstrates some of the important relationships between climatic factors (e.g. rainfall, temperature) and health effects, it is important to note that some of the most significant effects of climate change in the Pacific region, such as sea-level rise (which may, for example, impact on health by exacerbating overcrowding, cause mental health problems due to population displacement and lead to poor nutrition via effects on agriculture), are not included in the diagram.

Figure 1. Climate change and health linkages (adapted from Patz et al, 2000)



1. Fiji Ministry of Health

2. World Health Organization, Division of Pacific Technical Support, Suva

3. University of Otago, New Zealand

*. Address for Correspondence: lachlan.mciver@gmail.com

In 2004, the World Health Organization (WHO) supported a “Global Burden of Disease” assessment which estimated the annual mortality burden due to a range of diseases and exposures. The health impacts of climate change were included in this assessment and it was estimated that approximately 150 000 – 200 000 deaths worldwide, each year, were attributable to the effects of climate change (Kovats et al, 2005).

As can be seen in *Figure 1*, the health impacts of climate change include (but are not limited to): increased burden of water-, food- and vector-borne diseases; traumatic injuries and deaths from extreme weather events; increased burden of respiratory illnesses (due to infective causes and obstructive airways diseases); increased mental health problems (from loss of land, livelihoods and population displacement, as well as the mental health impact of natural disasters); compromised food security (leading to malnutrition) and heat-related illnesses. It is important to note that these problems will be borne disproportionately by certain vulnerable sectors of the population – the very poor, young children, the elderly, people with disabilities, people with preexisting illnesses (e.g. non-communicable diseases) and certain occupations (e.g. farmers, fishermen, outdoor workers) (Sheffield et al., 2011; McMichael, 2009).

In the Pacific, the region’s Health Ministers identified climate change and health as a key priority area at their 2009 meeting in Madang, Papua New Guinea, where they committed to, inter alia: assessing health vulnerabilities to climate change, strengthening health systems to manage the impacts of climate change and mobilizing communities to increase their resilience to these effects (Madang Commitment, 2009).

Fiji is involved in a seven-country global project, supported by WHO and the United Nations Development Programme (UNDP) with funding from the Global Environment Facility (GEF), entitled “Piloting Climate Change Adaptation to Protect Human Health” (PCCAPHH). This project aims to enhance the capacity of Fiji’s health sector to anticipate and respond effectively to four priority climate-sensitive diseases (CSDs): dengue fever, typhoid fever, leptospirosis and diarrhoeal disease. These CSDs are major public health concerns in Fiji.

This paper summarises the methodology, results and implications of the PCCPAHH project’s work to date examining the relationship between these diseases (the so-called “plagues” of Fiji) and climate variability in Fiji.

METHODOLOGY

The majority of the analytical work on the PCCAPHH project to date has focused on the construction of a climate-based early warning system (EWS) to provide timely information about possible epidemics of the aforementioned diseases. This process involved analysing the available data on climate (provided by the Fiji Meteorological Service) and CSD cases (from the National Notifiable Diseases Surveillance System - NNDSS), which was carried out via the following steps:

1. Calculation of historical disease incidence rates using NNDSS case numbers and Ministry of Health (MoH) population data.
2. Simple correlation (two-way scatterplots with straight lines-of-best-fit and summed residuals) of disease numbers and incidence with climate data, including:
 - a. National level: annual aggregate disease numbers and annual averages of climate data from 1957 to 2009; and
 - b. Subdivisional level: monthly aggregate disease numbers and monthly averages of climate data from 1995 to 2009.
3. Identification of disease “clusters” (patterns of unusual disease activity in a given area at a given time) at the medical area level between 1995 and 2009, using SaTScan (a space-time

analysis software package) and geographic information systems (GIS) technology to locate health centres and hospitals (“medical areas” within subdivisions).

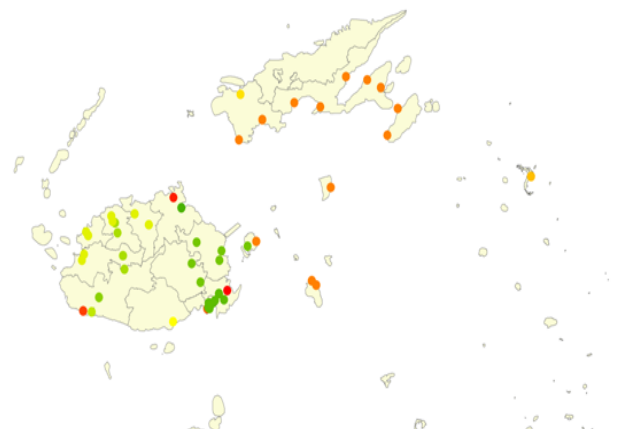
4. Identification of CSD “hotspots” – areas (at the subdivisional and medical area level) where two or more of the four priority diseases occurred at higher-than-average incidence, or in two or more clusters over the study period, or both.
5. Detailed analysis of CSD and climate data in “hotspot” subdivisions, using Stata (a statistical analysis software package) to perform time-series analysis, Poisson regression and lag functions.

RESULTS

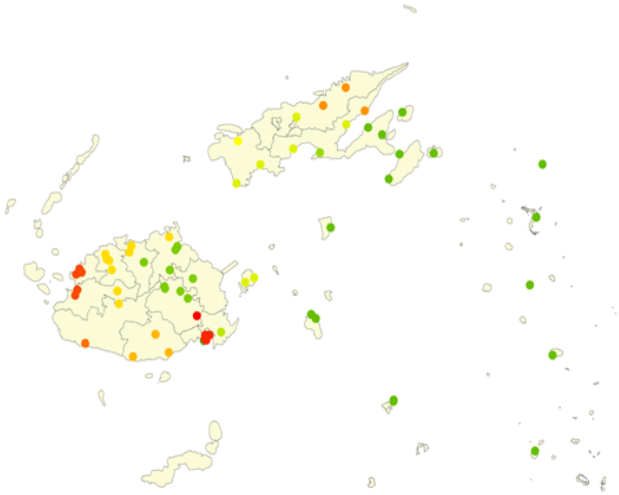
Review of the historical incidence patterns for the aforementioned diseases confirmed the epidemicity of dengue fever in Fiji and appeared to show alarming trends towards increasing incidence of both leptospirosis and typhoid, while diarrhoeal disease incidence showed no particular trend.

Space-time analysis of each of the four diseases over three five-year periods between 1995 and 2009 showed distinct “clustering”, as displayed in *Figures 2a-2d*. In this series of figures, each dot represents a “medical area” (as defined by the Fiji MoH) and each group of dots of the same colour represents a statistically significant “cluster” of cases in a circumscribed geographic region (medical areas reasonably close to each other) at a given time during the study period.

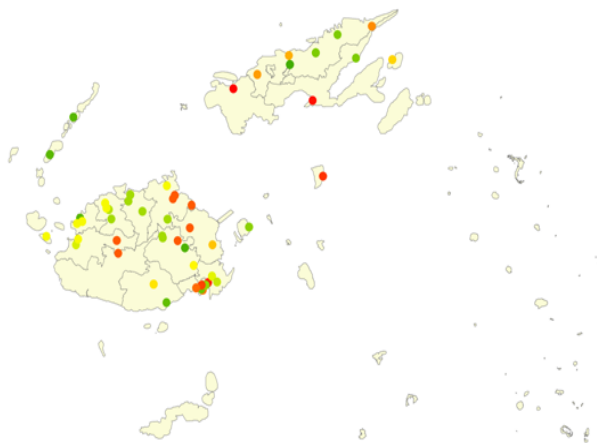
2a. Dengue fever “clusters” in Fiji (1995-2009)



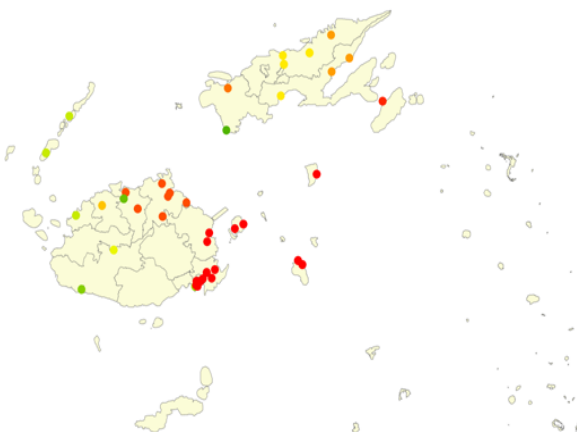
2b. *Leptospirosis “clusters” in Fiji (1995-2009)*



2c. *Typhoid “clusters” in Fiji (1995-2009)*



2d. *Typhoid “clusters” in Fiji (1995-2009)*



The process of reviewing historical incidence patterns and space-time clustering of the four diseases led to identification of a shortlist of “hotspot” subdivisions, which appeared to have increased burden of two or more of the CSDs in question. This list included Ba, Bua, Macuata, Ra, Suva, Tailevu, Tavua and Vunidawa. From this list, the two final “pilot site” subdivisions of Ba and Suva were selected for more detailed analysis of the relationship between climate and disease, via time-series and Poisson regression techniques.

Some examples of the intermediate outputs of this analysis process are displayed below in *Figure 3* (graphical time-series of leptospirosis, temperature and rainfall in Ba) and *Figure 4* (correlation of rainfall with diarrhoeal disease in Suva). A summary of the results of modeling monthly climate variables with monthly cases of diseases in the two subdivisions is presented in *Table 1*.

* The “model” line in each row gives the correlation coefficient for the “best” model combining the climate variables at monthly lags which give the highest correlation coefficient

** All results displayed significant to the $p \leq 0.05$ level.

Figure 3. *Monthly leptospirosis cases and climate (average maximum and minimum monthly temperatures in degrees Celsius; monthly rainfall in millimetres) in Ba subdivision (1995-2009)*

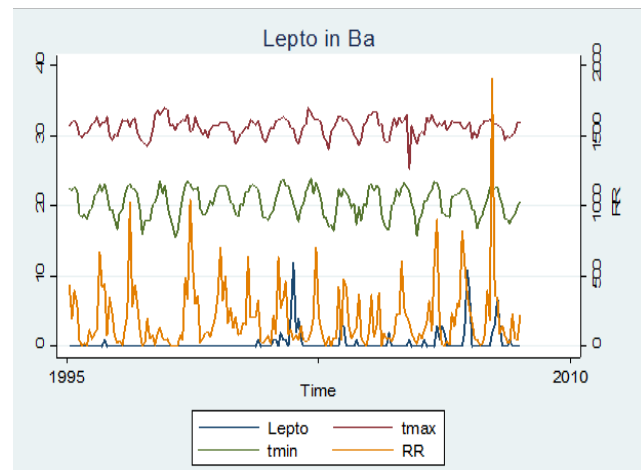
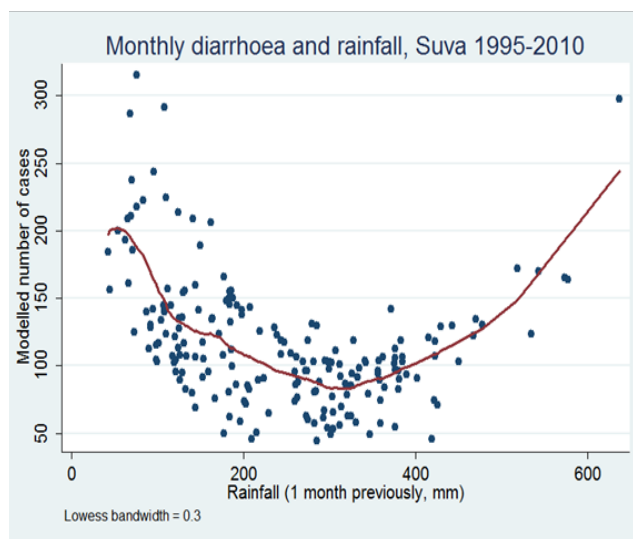


Table 1. Relationship between monthly climate variables (rainfall, maximum temperature, minimum temperature and humidity) at lags of up to three months with monthly cases of CSD's (1995-2009)

Disease	Subdivision	Climate variables/model*	Strength of association (pseudo-r ² value)**	
Dengue	Ba	Rainfall- lag 1,2,3 Maxtemp- lag 0,1,2,3 Mintemp- lag 2 Humidity- lag 1	0.3, 0.27, 0.32 0.29, 0.38, 0.32, 0.29 0.25 0.34	
		Model: rainfall, maxtemp, humidity at lag-1	0.39	
	Bua	Rainfall - lag 0,1,2, Maxtemp- lag 0,2,3 Mintemp- lag 0,1,2,3 Humidity- lag 0	0.4, 0.3, 0.37 0.37, 0.33, 0.31 0.35, 0.30, 0.32, 0.31 0.33	
		Model: rainfall, maxtemp, mintemp at lag-0	0.52	
	Lautoka	Rainfall- lag 1 Maxtemp- lag 1 Mintemp- lag 1	0.42 0.53 0.27	
		Model: combination of three lagged climate variables above	0.54	
	Suva	Rainfall- lag 2 Maxtemp- lag 3 Mintemp- lag 0,2 Humidity- lag 2	0.47 0.50 0.57, 0.52 0.47	
		Model: all four climvar's at lag-2	0.6	
	Diarrhoeal illness	Ba	Rainfall- lag 1 Maxtemp- lag 3 Mintemp- lag 3 Humidity- lag 1	0.1 0.06 0.07 0.14
			Model: model with all four lagged climvar's above	0.17
		Bua	Rainfall- lag 0 Maxtemp- lag 0,1,2, Mintemp- lag 0-3 Humidity- lag 2	0.12 all ~-0.10 all ~-0.10 0.12
			Model: rainfall, maxtemp, mintemp at lag-0	0.13
Suva		Rainfall- lag 1,3 Maxtemp- lag 0,3 Mintemp- lag 3	~0.4 " "	
		Model: three climvar's above at lag-3	0.41	
Leptospirosis	Ba	Rainfall- lag 2 Maxtemp- lag 1,2 Humidity- lag 1,2	0.3 0.32, 0.30 0.3, 0.3	
		Model: rainfall lag -2, mintemp lag-1	0.35	
	Bua	Rainfall- lag 0,2,3 Maxtemp- lag 0,3 Mintemp- lag 0,1,2,3 Humidity- lag 0,1	0.42, 0.4, 0.48 0.38, 0.45 0.4(all) 0.45, 0.40	
		Model: rainfall, maxtemp, mintemp at lag-3	0.59	
Typhoid	Ba	Rainfall- lag 1,2,3 Maxtemp- lag 0,3 Mintemp- lag 1,2,3 Humidity- lag 0,1,2,3	0.47, 0.63, 0.49 0.47, 0.49 0.46, 0.52, 0.46 0.48, 0.46, 0.47, 0.5	
		Model: rainfall, mintemp at lag-2	0.66	
	Bua	Rainfall- lag 0 Mintemp- lag 0,3 Humidity- lag 3	0.35 0.36, 0.36 0.35	

Figure 4. Monthly cases of diarrhoea vs monthly rainfall (lagged by 1 month) in Suva, based on a Poisson regression model. (NB. Solid red line is a Lowess smooth illustrating a typical “U-shaped” relationship).



Given the particular vulnerability of the Western Division to extreme weather events such as floods and droughts, additional modeling of the relationships between events such as tropical depressions, floods and droughts and cases of CSD's was undertaken for Ba subdivision. This analysis showed significant relationships between these events and epidemics of dengue fever and diarrhoeal disease in the subsequent month. These findings are presented as odds ratios in *Table 2*.

Table 2. Odds ratios of CSD outbreaks in the month following extreme weather events in Ba subdivision

Extreme weather event	Odds ratio (OR)* of CSD outbreak in the month following the event
Drought	Dengue fever: OR = 5.17 Diarrhoeal disease: OR = 9.0
Floods caused by tropical depressions	Dengue fever: OR = 10.57
All Floods	Diarrhoeal disease: OR = 3.5

* All results displayed significant to the $p \leq 0.05$ level

DISCUSSION

The PCCAPHH project's work described above examining the relationship between climate variables and cases of four CSDs has discerned some correlations between monthly temperature, rainfall, humidity and extreme weather events and monthly cases of leptospirosis, typhoid fever, dengue fever and diarrhoeal disease in several regions of Fiji.

This analysis builds on earlier work in the Pacific and elsewhere investigating the relationships between climatic factors and infectious diseases, including:

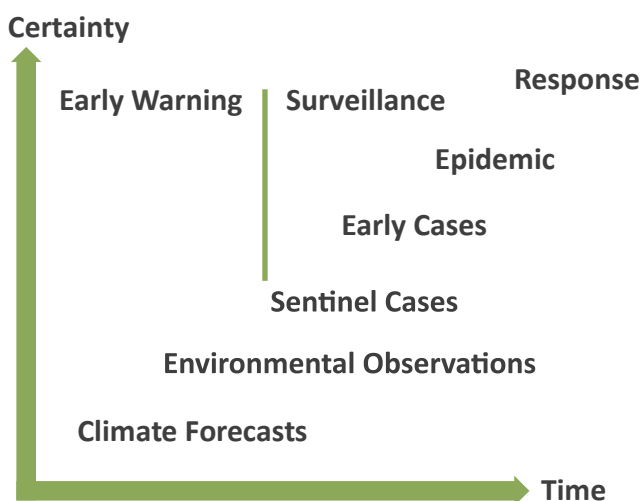
- modeling of dengue fever in the South Pacific showing a positive correlation between monthly temperature and rainfall, La Niña years and dengue fever outbreaks in ten countries, including Fiji (Hales et al., 1999), with comparable findings reported in several other regions of the world such as the Caribbean (Depradine et al., 2004), South America (Chowell et al., 2011) and South-East Asia (Thai et al., 2010);
- a well-known study of diarrhoea in infants in Fiji showing a positive association between incidence of diarrhoea, extremes of rainfall and increasing temperature (Singh et al., 2001), a finding consistent with earlier work in Peru (Checkely et al., 2000) and Bangladesh (Hashizume et al., 2008)
- the observation that Fiji experiences outbreaks of leptospirosis after cyclones, with generation of the hypothesis that this correlates with the corresponding increase in agrarian activities that takes place following a natural disaster (Ghosh et al., 2010), noting that this is consistent with some published studies reporting higher rates of leptospirosis following rainfall elsewhere in the tropics (Lhomme et al., 1996, Desvars et al., 2011).

The empirical modeling to date indicates that, given the observed lag between the exposure (climate variables) and the outcome (monthly cases of disease), it may be possible to use climate

information (including forecasts) to predict epidemics of these four important communicable diseases in Fiji. This idea has a long history, with models pioneering the incorporation of rainfall into malaria early warning systems in India dating back almost a century (Gill, 1923). The process of compiling such models, including key components and steps for testing and evaluation, has been well described elsewhere (Campbell-Lendrum, 2005).

While, clearly, the explanatory power of climatic factors in predicting CSD epidemics is typically small, and myriad other factors (such as population movements, herd immunity, vector abundance and behaviour to name just a few) all form part of a more complete, biological or “mechanistic” model of disease, nevertheless the ability to use climate data to add an extra, “upstream” layer to standard disease prevention, surveillance and response capacity may prove valuable in the Fiji public health context (*see Figure 5*).

Figure 5. Early warning systems adding value to traditional disease surveillance (WHO, 2008)



It must be made clear, however, that both the analyses above and the potential for these to inform any prospective disease early warning systems are limited by the quality and quantity of the data, particularly the health data.

One of the major issues is the mismatch between the notified () and the laboratory-confirmed case data for these and other diseases (including

influenza). This is a well-recognised problem in Fiji, resulting from the gradual strengthening of the laboratory diagnostic capacity in the country (which lies predominantly within the National Centre for Communicable Disease Control and the major hospitals) and the inconsistencies in reporting of notifiable diseases, due to problems with case definitions, timeliness of report submissions, the attention given to diseases around the time of outbreaks and other factors. Of particular relevance to this project is the fallibility of the NNDSS in accurately and consistently recording cases of dengue fever, leptospirosis and typhoid fever – all of which can be difficult to diagnose clinically without laboratory confirmation, particularly in the context of an outbreak (which can lead to over-diagnosis of the disease in question due to heightened awareness of patients and clinicians alike, as well as potentially under-diagnosis of diseases with similar clinical presentations, as demonstrated in a study of leptospirosis in patients presenting with dengue-like illnesses in Puerto Rico (Bruce et al., 2005)). It could also be argued that the lack of routine laboratory confirmation of diagnoses of these three diseases prior to approximately 2006 means that there is a genuine lack of information regarding their true incidence in Fiji.

A critical issue in the study of typhoid fever in Fiji is the apparent sudden rise in cases from around 2005-2006. Possible causes for this include: a true increase in the number of cases of typhoid in Fiji, far in excess of that which may be expected due to population growth; increased awareness on the part of the public and/or health professionals about the risk factors, symptoms and clinical picture of typhoid (NB. this may have the effect of either accurately recognising cases which would have previously gone unrecognised, or incorrectly diagnosing non-typhoid cases as typhoid); a lapse in the typhoid vaccination regimen; and antibiotic resistance of the pathogenic organism, among other factors.

There are occasional, unexplained gaps in both the health and climate data utilised so far; it is not clear whether, in the case of the disease data, these represent “no cases” and/or “unreported cases”

(for the climate data presumably a breakdown in communication and/or technology is to blame). There have also been inconsistencies in the manner in which the health data have been recorded over the study period (most likely due to staff turnover); there is the potential – and intention – for this project to contribute towards the standardisation of disease data record-keeping for improved use in the future.

CONCLUSION

Elucidating the relationships between climatic variables such as temperature, rainfall, humidity and extreme weather events and CSDs such as leptospirosis, typhoid fever, dengue fever

and diarrhoeal disease in certain regions of Fiji may allow the construction of climate-based early warning systems to reduce the impacts of epidemics of these disease, as well as estimates of their respective future burdens due to climate change. Such a system would ideally form part of a suite of health system strengthening activities as the health sector adapts and increases its own resilience to climate change.

It is hoped that this information may be used to inform public health professionals and communities to reduce the health risks posed by climate variability, extreme weather events and climate change in Fiji.

REFERENCES

1. Bruce MG, Sanders EJ, Leake JAD, Zaidel O, Bragg SL, Aye T et al. *Leptospirosis among patients presenting with dengue-like illness in Puerto Rico. Acta Tropica* 2005; 96(1): 36-46
2. Capon, A., and Hanna, E. (eds). *Climate change: an emerging health issue. NSW Public Health Bulletin* 2009; 20 (1-2): 1-4
3. Checkley W, Epstein L, Gilmam R, Figueroa D, et al. *Effects of El Niño and ambient temperature on hospital admissions for diarrhoeal diseases. Lancet* 355:442–450 (2000).
4. Chowell, G., Cazelles, B., Broutin, H., & Munayco, C. V. (2011). *The influence of geographic and climate factors on the timing of dengue epidemics in Perú, 1994-2008. BMC infectious diseases* (Vol. 11, p. 164). doi:10.1186/1471-2334-11-164
5. Depradine C, Lovell E. (2004) *Climatological variables and the incidence of Dengue fever in Barbados. Int J Env Health Research* 14:429–441.
6. Desvars A, Jégo S, Chiroleu F, Bourhy P, Cardinale E, Michault A. *Seasonality of human leptospirosis in Reunion Island (Indian Ocean) and its association with meteorological data. PLoS One* 2011; 6(5):e20377. Epub 2011 May 31
7. Ghosh A, Khan S, Kishore K. *Leptospirosis in Fiji: incidence between 2000 and 2007 and review of literature. Fiji Med J* 2010; 29(1): 8-14
8. Gill CA. (1923) *The prediction of malaria epidemics. Indian Journal of Medical Research*, 10:1136–1143.
9. Hales S, Weinstein P, Souares Y, Woodward A. *El Niño and the dynamics of vectorborne disease transmission. Environ Health Perspect* 1999; 107(2): 99-102
10. Hashizume, M., Wagatsuma, Y., Faruque, A. S. G., Sack, D. a., Hayashi, T., Hunter, P. R., & Armstrong, B. (2008). *Factors determining vulnerability to diarrhoea during and after severe floods in Bangladesh.*
11. *Journal of Water and Health*, 6(3), 323. doi:10.2166/wh.2008.062
12. Kovats RS, Campbell-Lendrum D, Matthies F. *Climate change and human health: estimating avoidable deaths and disease. Risk Anal.* 2005; 25: 1409–1418
13. Kuhn K, Campbell-Lendrum D, Haines A, Cox J. *Using climate to predict infectious diseases epidemics. WHO*, 2005
14. Lhomme V, Grolier-Bois L, Jouannelle J, Elisabeth L. *Leptospirosis in Martinique from 1987 to 1992: results of an epidemiological, clinical and biological study. Med Mal Infect* 1996; 26: 94-98
15. McMichael AJ. *Climate change and human health. In: Commonwealth Health Ministers Update 2009. Pro-Book Publishing (on behalf of Commonwealth Secretariat)*
16. Patz, J. et al. *The potential health impacts of climate variability and change for the United States: executive summary of the report of the health sector of the US National Assessment. Environ Health Perspect*, 108: 367–376 (2000)
17. Sheffield PE, Landrigan PJ. *Global climate change and children's health: threats and strategies for prevention. Environ Health Perspect* 2011; 119(3): 291-298
18. Singh RBK, Hales S, de Wet N, Raj R, Hearnden M, Weinstein P. *The influence of climate variation and change on diarrhoeal disease in the Pacific islands. Environ Health Perspect* 2001; 109(2): 155-159
19. Thai KT, Cazelles B, Nguyen NV, Vo LT, et al. *Dengue dynamics in Binh Thuan province, southern Vietnam: periodicity, synchronicity and climate variability. PLoS Negl Trop Dis* 2010; 4: e747
20. World Health Organization. *Protecting our Health from Professionals Climate Change:*
21. *a Training Course for Public Health* (2008). Accessed online http://www.who.int/globalchange/training/health_professionals/en/index.html, August 2011

Chapter Nine

Paper 6: Early warning systems for climate-sensitive infectious diseases in Fiji: lessons learned and next steps

Prelude

This paper, the second in the two-part series published in the *Fiji Journal of Public Health*, provides a critical appraisal of one of the strategies for health adaptation most commonly postulated in the literature – climate-based early warning systems for infectious disease epidemics – viewed from the perspective of Fiji’s climate change and health adaptation plan.

Innovative statistical models were used to generate a “risk index” in the case of diarrhoeal diseases in two of Fiji’s “hotspot” subdivisions; the paper goes on to describe a hypothetical mechanism for the communication of such warnings based on system triggers and information feedback loops.

However, the paper makes clear that despite the enthusiasm for early warning systems in the international climate change and health literature, their use may be limited in small, developing countries, whose health systems are already stretched to or beyond capacity, and where small populations weaken the statistical power of such models. In these contexts, advance warning is rendered useless by the lack of surge capacity to enable effective intervention(s) to avoid the possible health risk alerted by the system.

Thus, as this paper points out, a cautious, consultative approach is required prior to the investment of substantial time and resources into developing early warning systems as adaptation strategies for Pacific island countries.

The candidate’s estimated proportional contributions to this paper were as follows:

Research design:	50%
Analysis and interpretation:	50%
Authorship of paper:	70%

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Reference: McIver L, Hales S, Dear K, Kim R. Early warning systems for climate-sensitive infectious diseases in Fiji: lessons learned and next steps. *Fiji Journal of Public Health* 2014; 3(3): 8-16.

Early warning systems for climate-sensitive infectious diseases in Fiji: lessons learned and next steps

McIver. L¹, Hales. S², Dear. K³ and Kim. R⁴

Keywords:

Abstract

Background: The Piloting Climate Change Adaptations to Protect Human Health (PCCAPHH) project in Fiji has as one of its three main objectives the establishment and trialling of climate-based early warning systems for climate-sensitive infectious diseases, which have been tested and implemented for climate-sensitive health risks such as heatwaves, dengue fever and cholera elsewhere in the world.

Aims: This paper summarises the relevant literature on climate-based disease early warning systems in the Pacific context, and describes the methodology and results of the analysis of climate and diarrhoeal disease data for Ba and Suva subdivisions – the two PCCAPHH project pilot sites – in an effort to determine whether a climate-based early warning system for diarrhoea may be implemented by the Fiji Ministry of Health.

Methods: Negative binomial regression of climate and diarrhoeal disease data was undertaken, and models built incorporating climatic factors at different temporal (monthly) lags. The best models for Ba and Suva subdivisions were used as the basis for the construction of a “diarrhea risk index” based on an anomaly function, which used as a reference the observed numbers of cases over a long-term trend.

Results: Diarrhoea risk index models were constructed for both Ba and Suva subdivisions, and an early warning system mechanism based on these models and novel linkages between key stakeholders (including the Fiji Meteorology Service, Fiji Ministry of Health and community agencies) is proposed.

Conclusion: Climate-based early warning systems, such as those proposed for diarrhoeal disease in these two pilot sites in Fiji, form part of a suite of health system adaptation measures which may be used to protect human health from short-term hydro-meteorological disasters such as floods, as well as the longer term detrimental impacts of climate change.

Introduction

Early warning systems (EWSs) are a concept originating in the field of disaster risk reduction and are predicated upon the provision of timely information enabling actions to minimise the impact of an anticipated event. EWSs have long been considered to be one of the key opportunities for the health sector with respect to climate change and health adaptation (Connor et al., 2010; WHO, 2003), including in the setting of small island developing states (SIDS) (Ebi et al., 2006).

The empirical basis of an early warning system rests on three fundamental assumptions: that of biological plausibility, wherein environmental or other natural phenomena are logically and provably linked to a particular hazard or outcome; that of temporal lag, whereby sufficient time lapses between the warning signs and the event occurrence to enable appropriate action; and that of intervention feasibility, which implies that it is possible to take anticipatory or avoidant action to minimise the impact of the event.

The common ground between disaster risk reduction and climate change adaptation is increasingly recognised within national and international adaptation frameworks, including those issued by organisations such as the United Nations Office for Disaster Risk Reduction (UNISDR), the International Federation of the Red Cross (IFRC) and the World Health Organization (WHO). In the Pacific region, several countries have compiled Joint National Action Plans for climate change and disaster risk reduction (JNAPs), including Cook Islands, Marshall Islands, Nauru, Niue, Tonga and Tuvalu (SPREP, 2013), and a forthcoming report by WHO entitled Human Health and Climate Change in Pacific island countries summarises the efforts and plans of Pacific island countries (PICs) to increase the resilience of health systems to both climate change and natural disasters (WHO, in press).

Disaster risk practice is therefore a suitable starting point for consideration of climate-based EWSs for health risks (e.g. epidemics of communicable disease), since there are established resources, policies and experience in this field.

EWSs have been defined as: “*The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss*” (IFRC, 2012).

Implicit in the idea of an EWS is a high degree of shared understanding about the nature of the hazard, the reasons for the warning and the nature of action, including preparation that is needed to reduce loss or harm. An EWS must be based on sound knowledge of risks and the risks must be able to be monitored or forecast. But EWSs are more than just prediction tools; to be effective, they must include mechanisms to disseminate and communicate critical information, and enable interventions that are proactive (as opposed to reactive or responsive), appropriate, timely and sufficient (Basher, 2006).

There is increasing international interest in EWSs. Many international agencies and non-government organisations (NGOs) are developing programmes and resources to support the expansion of early warning capacity. This expanded interest appears to be based in part on the effectiveness of early warning systems in reducing mortality from severe weather events such as storms (Ebi & Schmier, 2005), and more recent observations of a similar potential for such reductions in relation to heatwaves (Huang et al., 2013).

Climate-based EWSs for health hazards such as communicable disease epidemics are a relatively recent development, and are less well developed than those used to anticipate the health impacts

¹Australian National University, Australia

²University of Otago, NZ

³Duke Kunshan University, China

⁴WHO, Suva, Fiji

*Address of Correspondence: lachlan.mciver@gmail.com

of natural disasters and extreme weather events. There is convincing evidence that many communicable diseases of global concern are climate-sensitive, including vector-borne diseases such as dengue fever (Chowell et al., 2011; Hii et al., 2012) and malaria (Thomson et al., 2006; Yu et al., 2014); zoonoses such as leptospirosis (Weinberger et al., 2014); and water- and food-borne diseases causing diarrhoeal illnesses and other gastrointestinal infections (Hashizume et al., 2007; Singh et al., 2001; Wu, Yunus, Streatfield & Emch, 2013).

Each of these climate-sensitive diseases differ in terms of the empirical basis for early warning systems – i.e. the above mentioned fundamental assumptions of biological plausibility, temporal lag and intervention feasibility. To take one example, vector-borne diseases such as dengue fever and malaria are driven, in part, by the relationship between mosquito life cycle breeding habitats, larval multiplication, biting behaviour and viral replication, all of which may be affected by environmental factors such as rainfall, temperature and humidity (Bouzid et al., 2014; Hunter, 2003). However, these factors together form only part of a much larger and more complex ecological system which includes human behaviour,

individual and herd immunity, spatial dynamics, intervention measures and myriad other factors. In another example, the case of diarrhoeal diseases, the many pathogens causing gastrointestinal infection may be affected by temperature – with many bacteria and viruses replicating faster at higher temperatures – and rainfall, particularly in the extreme, i.e. scarcity (e.g. drought) and abundance (e.g. flood), when drinking water sources are more prone to contamination and the safety of water, sanitation and hygiene systems are compromised (Falagas et al., 2010; Wu et al., 2013).

While it is outside the purview of this paper to elaborate in further detail the complexities of these ecological links, it is clear from the rapidly expanding body of evidence on the topic that environmental and climate factors are significant links in the mechanistic models of disease, and are thus correlated, to varying degrees, with climate-sensitive disease dynamics.

There are also sound theoretical reasons to expect that early interventions might be beneficial to reduce the burden of climate-sensitive infectious diseases. A framework for the development of EWSs for climate-sensitive infectious diseases has been proposed (see Figure 1).

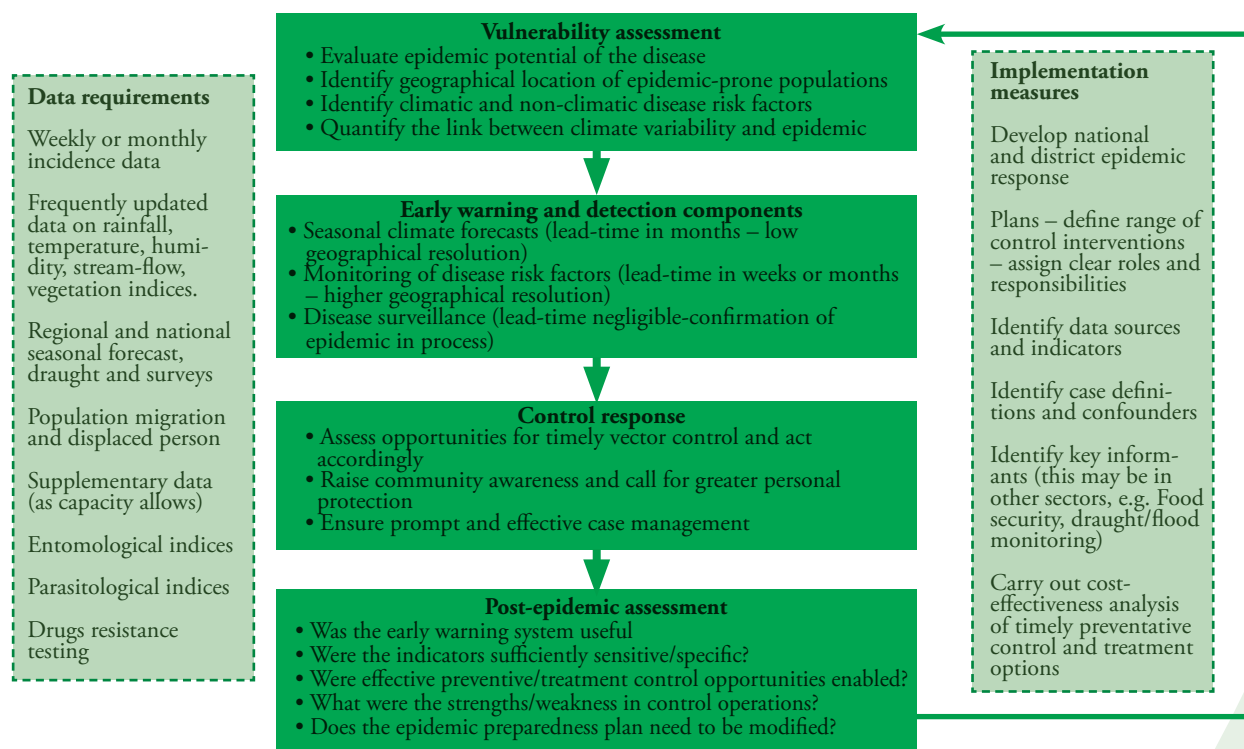


Figure 1. Framework for developing EWSs for climate-sensitive diseases (Source: Kuhn et al., 2005)

Major national and international collaborative efforts are underway to develop climate-based models for early warning of outbreaks of, inter alia, malaria, dengue fever, diarrhoeal disease and meningitis (WHO & WMO, 2012), including some Pacific-specific models, such as that developed for dengue fever in New Caledonia (Descloux et al., 2012). However, the science of climate-based disease EWSs is still in its infancy, scant progress has been made to date in testing and evaluating such models and, despite the abundant recommendations for the utilisation of EWSs as health adaptations to climate change, most such systems remain in the theoretical domain at present.

This paper discusses the development of a climate-based EWS for diarrhoeal illness in Fiji.

Fiji is one of seven countries involved in a global climate change and health adaptation pilot project entitled Piloting Climate Change Adaptations to Protect Human Health (PCCAPHH), along with Barbados, Bhutan, China, Jordan, Kenya and Uzbekistan. The project is implemented by the Fiji Ministry of Health (MoH), funded by the Global Environment Facility (GEF), and facilitated by WHO, in collaboration with the United Nations Development Programme (UNDP). The project's overall aim "... to increase adaptive capacity of national health system institutions, including field practitioners, to respond to climate-sensitive health risks" is to be achieved via three main outcomes, the first of which is to devise an EWS "... to provide reliable information on likely incidence of climate-sensitive diseases".

The PCCAPHH project in Fiji focuses on four priority climate-sensitive communicable diseases – diarrhoeal disease, dengue fever, leptospirosis and typhoid fever – that are collectively considered to be the country’s “four plagues”. An extensive review of these four diseases was conducted in the early stages of the project, including the epidemiology, distribution and climate-sensitivity of each disease, and the identification of “hotspot” subdivisions and subsequently two project pilot sites, where the burdens of disease appeared to be highest and/or the climate-sensitivity seemed strongest, and the potential for public health intervention(s) to reduce the contemporary and future burden of such climate-sensitive diseases was deemed greatest (McIver et al., 2012).

In this paper, the process of devising and implementing an EWS for diarrhoeal disease in the two regions of Fiji selected as the PCCAPHH project pilot sites is described, including the methodology and results of statistical modelling of climate and disease data, and the mechanism by which such a system may be implemented in Fiji.

The analysis and discussion that follow are limited to consideration of the climatic drivers of diarrhoeal disease in two regions in Fiji. It must be understood that the environment in general, and climate in particular, form only a relatively small piece of the overall picture of the epidemiology of diarrhoeal disease in Fiji.

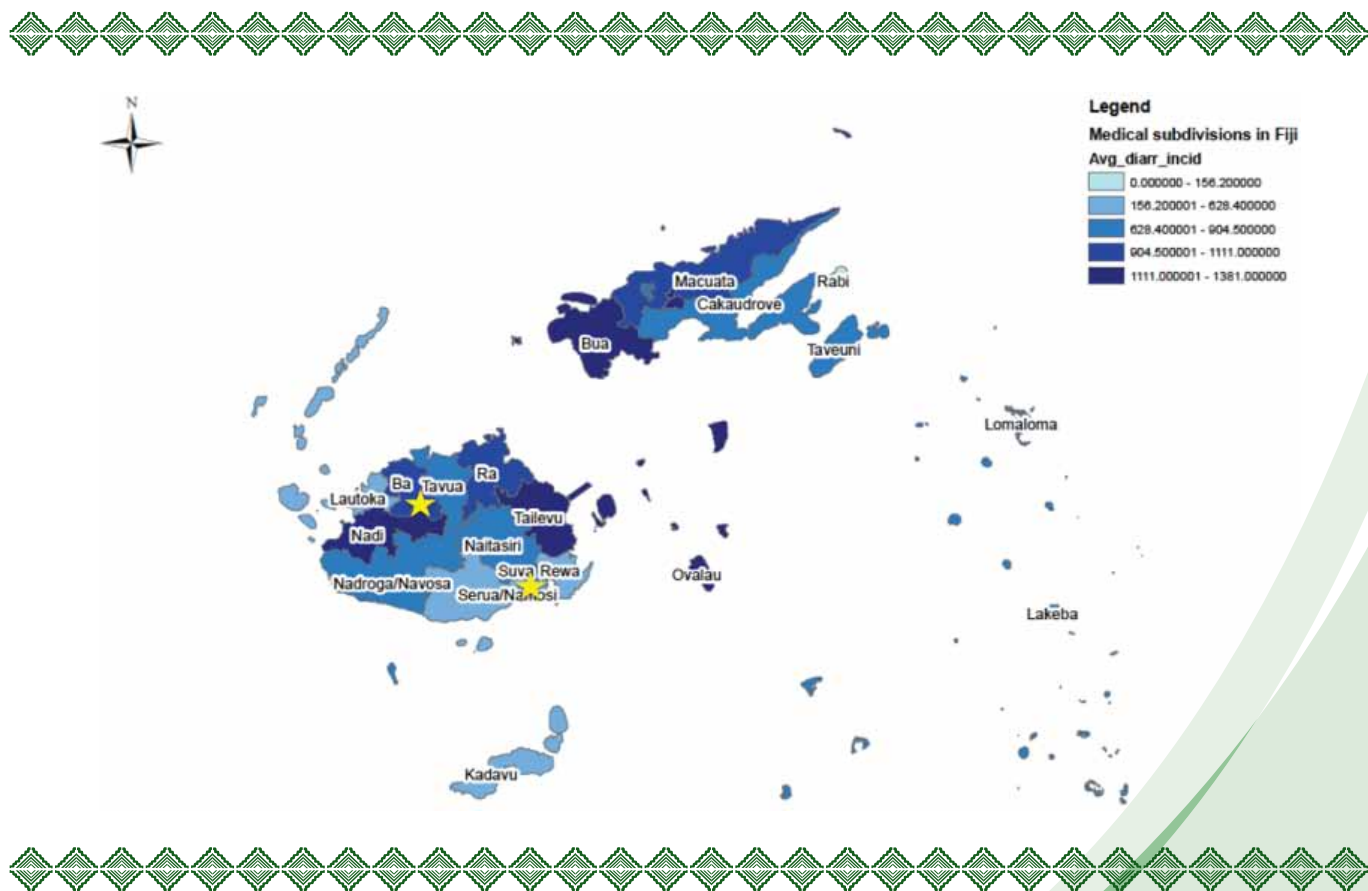
There are many other, important factors that contribute to the burden, or alleviation, of diarrhoeal disease in these two pilot sites and other regions in Fiji; detailed discussion of these

factors is outside the purview of this paper, which focuses on the potential for climatic factors to form the basis of an EWS as a pilot strategy for climate change adaptation in Fiji.

In addition, the implications of EWSs as a health adaptation strategy in the context of Pacific SIDS are discussed, including some of the foreseeable challenges and opportunities. It is hoped that the lessons learned from this pilot project in Fiji will prove useful in the wider landscape of climate change and health adaptation, both in the Pacific region and in other settings around the world.

Methods

This study focussed on the potential for climate-based early warning systems to provide timely information regarding increased incidence of diarrhoeal disease in the two PCCAPHH project pilot sites of Ba and Suva subdivisions (see Map 1). A number of key factors determined the selection of these two subdivisions as pilot sites for the project. Principal among these factors were the differing climates on the two sides of the main island of VitiLevu without hyphon (Suva being in the wetter south-west region and Ba in the drier north-east), the burden of diarrhoeal diseases and the other three climate-sensitive diseases prioritised in the PCCAPHH project (dengue fever, leptospirosis and typhoid fever), and the climate-sensitivity of the diseases themselves – i.e. the extent to which each of the diseases appeared to be associated with climatic factors and thus amenable to intervention with early warning (McIver et al., 2012).



Map 1. Regions (medical subdivisions) of Fiji shaded according to average annual diarrhoeal disease incidence (per 100 000 population) over the period 1995-2009, with stars indicating Ba and Suva subdivisions.

Data

Available weather variables included: monthly average of daily minimum (Min) and maximum (Max) temperatures (°C); monthly average of daily average relative humidity (RH) (%); and total monthly rainfall (RR) (mm). The rainfall variable was transformed using $\log_{10}(1+RR)$ due to substantial skew, thus limiting the effects of outliers on model validity. The monthly timescale was selected for two principal reasons: first, there is a strong precedent in the literature on environmental epidemiology and time series analysis supporting the use of monthly temporal windows; second, both meteorological and disease data were available in raw form at monthly average and/or aggregate time-scales, whereas daily or weekly timescales would have required some form of imputation or transformation of one of the two datasets, thus introducing another potential source of error. Missing weather values for Ba were imputed using linear regression on the other three variables, the previous month's value of the missing variable, and year and month as factors. Where other weather variables were also missing in the same month, the regression was limited to year, month and the previous value. In Ba, one implausibly low value of maximum temperature was deleted (April 2006, 25.3°C), then imputed (to 32.1°C).

Diarrhoeal disease data was sourced from Fiji's National Notifiable Disease Surveillance System (NNDSS). Weekly notifications of the number of cases of diarrhoeal disease from all medical areas within each subdivision over the study period of 1995-2009 were collated into monthly datasets. Given that the NNDSS is the standard reporting system for notifiable diseases across Fiji, it is assumed, for the purposes of this study, that both the validity of the data and potential sources of bias are consistent between the two subdivisions under study. Similarly, while there may be intrinsic differences between the scope and effectiveness of public health practice (including data collection and practical action) between the two subdivisions, it is outside the scope of this study to address these and other related sources of error and bias, so it is assumed that both subdivisions have equal capacity to report and react to information.

The models presented below analyse total monthly reported cases of diarrhoea disease ignoring age, sex and race, and attempt to capture the variation in these rates as functions of time (long-term trend and month of the year) and recent weather (up to 12 months past). Such models are purely empirical, in that they do not attempt to take into account biological or other mechanistic factors which may confound or otherwise affect the relationship between climate variables and cases of diarrhoeal disease.

Model building

Monthly disease rates were modelled using negative binomial regression. This class of model is standard for analysing count data that are overdispersed, i.e. that are more variable than a Poisson model would assume. Long-term trend was captured using orthogonal natural splines with six degrees of freedom, generated using the "splines" function in Stata - a data analysis and statistical software package (Stata Corporation, College Station, Texas).

Annual cycles were captured using cosinor analysis, that is, sine and cosine functions that repeat once, twice or more within a year and are assumed to apply identically in every year. The required number of harmonics was determined by comparison with a model that treated months as a 12-level factor: the number of harmonics was set to the minimum, such that the factor model was not a statistically significant improvement, since this indicated that the cosinor model had captured all important cyclic annual variation in disease rates. In a baseline model for each disease analysed in each location, each of the four weather variables was modelled as distinct effects at lags 1 (the previous month) to lag 12 (one year ago). Lag 0 (the current month) was not used in the models as it would not be available for predictive purposes, i.e. early warning.

The baseline model thus included trend, cycles, and up to twelve monthly lags for each weather variable.

From this baseline model, simple summaries of one or more weather variables were identified visually. For example, if a certain range of lags appeared to have a strong and similar effect on disease risk, then the average over those months was deemed a reasonable representation of the effect of that variable for the purpose of modelling that disease in that location. These summary measures, or weather indicators, were then used in a new model to obtain coefficients and to re-estimate monthly effects.

An index was then constructed incorporating the monthly effects (i.e. time of year) and the weather indicators with their coefficients. The association of past disease rates with the index was examined in order to locate a threshold above which a warning of impending disease might be issued.

Alternative methods for model-building and validation were considered, including a binary outcome measure (e.g. epidemic month/period versus non-epidemic month/period), and prospective validation. The authors concluded that the diarrhoea anomaly and risk index approach outlined above, and elaborated in the Results section below, provided the best opportunity for piloting an EWS for diarrhoeal disease in Fiji. Future work for the PC-CAPHH project team will include prospective validation of this model, to explore the sensitivity and specificity of the warning capacity of the models.

Results

Substantial numbers of cases of diarrhoea were reported in all twelve months of the year in both subdivisions. While a certain amount of natural variability is to be expected with any disease, the analysis above attempted to control for this natural variability to elucidate the proportion of disease variability attributable to climatic factors. Thus, in the graphs that follow (Figures 2 and 3), the absolute numbers of cases of diarrhoeal disease are less important than the trends, which have been adjusted to best capture the contribution of climatic factors to disease activity.

It is important to note that, despite the differences in climate between the two pilot sites, the overall climate in Fiji is tropical, with a wet season from approximately November to April; diseases such as diarrhoeal illness typically increase during this period in Fiji and elsewhere in the Pacific (McIver, 2014)

In Ba subdivision, cosinor terms with four degrees of freedom (annual and half-yearly cycles) proved sufficient to capture annual cycles (Figure 2).



Figure 2. Monthly counts of diarrhoea cases in Ba subdivision (1995-2009), adjusted for weather variables and annual cycles (cosinor terms with four degrees of freedom, with spline trend of six degrees of freedom). NB. January values shown as solid circles.

In Suva, once again cosinor terms with four degrees of freedom were sufficient (see Figure 3).

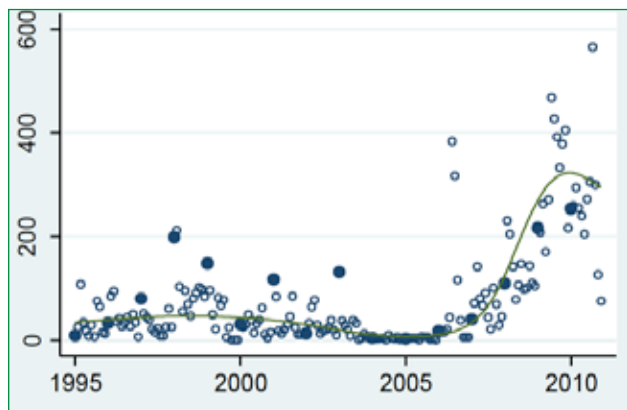


Figure 3. Monthly counts of diarrhoea cases in Suva subdivision (1995-2009), adjusted for weather variables and annual cycles (cosinor terms with four degrees of freedom, with spline trend of six degrees of freedom). NB. January values shown as solid circles.

Table 1 shows the results from significance testing of the basic model.

Table 1: Statistical significance of weather variables (lags 1 to 12, 12df Wald test) in predicting disease frequency.

p-value	Suva	Ba
	Diarrhoea	Diarrhoea
Min	0.063	<0.001
Max	0.17	<0.001
RR	<0.001	0.001
RH	0.004	0.098

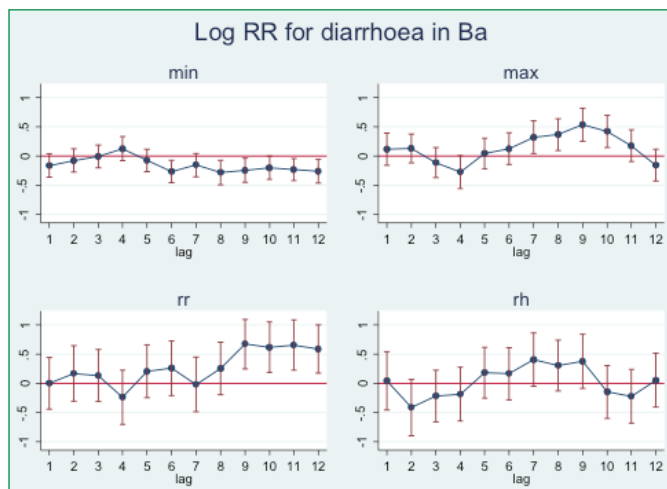


Figure 4. Coefficients for lagged weather variables in Ba (with 95% CI). The graph for humidity (rh) shows rate ratio per 10 percentage points of relative humidity

The traces of parameter estimates for the four weather variables in Ba (Figure 4) suggested use of simple predictive indicators. The coefficients were estimated by regression using these indicators:
 Imin = average of monthly minimum temperature over lags 6 to 12 (seven months): coefficient -0.447
 Imax = average of monthly maximum temperature over lags 7 to 10 (four months): coefficient 0.782
 Irr = average of log10-transformed monthly rainfall over lags 9 to 12 (four months): coefficient 1.18
 RH: not used.

In addition, an adjustment K(m) for each month m is to be applied, based on a fitted cosinor function. The resulting diarrheal risk index for Ba was calculated as:
 $DRI_{Ba} = K(m) + (-0.447) \times I_{min} + (0.782) \times I_{max} + (1.18) \times Irr$

This index expresses short-term variation in expected incidence of diarrhoea, against a background of more slowly varying disease rate. Therefore, to assess its performance and to identify a diarrhoeal risk alert threshold, the index's value in relation to the ratio of observed cases to the local trend was considered. This ratio, termed "Diarrhoeal Anomaly", is shown in Figure 5.

Since the index is based only on month of the year and weather values at least six months in the past, the index can be projected up to five months into the future. For instance, assuming that in May the weather data for April are available, then the index can be calculated as far ahead as October.



Figure 5. Diarrhoeal anomaly in Ba (rate relative to trend) against risk index calculated from weather data at least six months prior to the month of prediction.

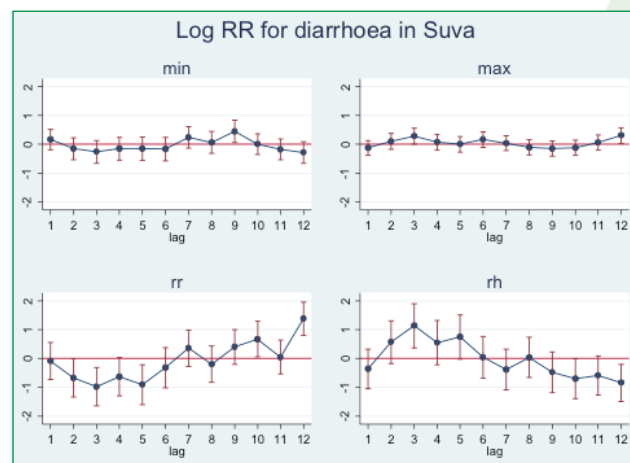


Figure 6. Coefficients for lagged weather variables in Suva (with 95% CI). The graph for rh shows rate ratio per 10 percentage points of relative humidity

The traces of coefficients for Suva (Figure 6) suggest no effect of temperature, confirming the significance test. Indicators for RR and RH might be calculated as the difference between lag 3 and lag 12, for both variables, i.e. $Irr = RR_3 - RR_{12}$ (using RR on the log scale); and $Irh = RH_3 - RH_{12}$. Refitting the model using just these two indicators of weather, plus trend and cycles, gives coefficients -1.00 for Irr and $.0815$ for Irh .

Thus the diarrhoeal risk index for Suva is calculated as:

$$DRI_{Su} = K(m) + (-1.00) \times Irr + (0.0815) \times Irh$$

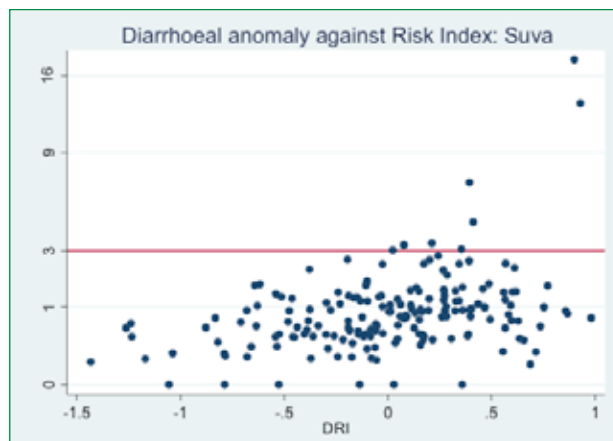


Figure 7. Diarrhoeal anomaly in Suva (rate relative to trend) against risk index calculated from weather data at least three months prior to the month of prediction.

Discussion

EWS have long been considered one of the most promising areas for innovation in the field of climate change and health adaptation. Climate-based EWSs represent both a challenge and an opportunity for the health sector, in that they may improve the sector's ability to anticipate events such as epidemics, thus reducing the overall health impact thereof.

There are a number of climate-sensitive infectious diseases of international public health concern in the context of climate change; the majority of these are the subject of various types of research related to climate-based EWSs in different parts of the world (Grasso et al., 2012). While a significant proportion of this research has focused specifically on cholera, diarrhoeal disease more broadly has not yet attracted significant research attention in relation to EWS development.

The work undertaken by the PCCAPHH project, and the mathematical models of diarrhoea risk described above in Suva and Ba – two regions with quite different climates and contrasting socio-demographic indicators – may pave the way for trialling a climate-based EWS for diarrhoeal disease in Fiji.

At a conceptual level, there are four distinct questions or tasks in designing an EWS for climate-related health issues. These involve identifying:

- the relevant risk(s) (what it is, where does it exist, and crucially, how important is it?);
- whether it is possible to monitor and/or forecast the risk(s) with sufficient accuracy;
- whether it is possible to communicate the risk in a timely and effective way; and
- whether the population or target sector is able and willing to respond to the communications in a timely and effective way.

The questions above relate to the key components of a public health EWS, as described by Ebi and Schmier in 2005 (see Table 2).

Table 2. Key components of an early warning system for public health (Source: Ebi & Schmier, 2005)

Component of EWS	Key considerations
Meteorological identification and forecasting	Type of event Risk of event (probability versus impact) Accuracy Timing
Prediction of possible health outcomes	Modelling functions of climatic factors and disease risk (e.g. diarrhoea risk index, as described above)
Response plan	Where will interventions be implemented? When (including thresholds for action)? What interventions are to be triggered? How will the actions be implemented? Implemented by whom and communicated to whom?
System evaluation	Monitoring and evaluation of system components and overall effectiveness? Cost-benefit analysis/economic effectiveness

In Fiji, the main provider of meteorological analysis and forecasting is the Fiji Meteorology Service (FMS), which has been a key partner in the PCCAPHH project. In collaboration with the FMS, the MoH may be in a position to trial a climate-based EWS for diarrhoeal disease in one or both of the project pilot site subdivisions, based on the models described above, with a lead-time of approximately three to five months for anticipatory interventions to reduce the burden of disease.

For example, in Ba, it appears that high disease risk (rates more than double the current trend) tend to occur at index values above approximately 17.8. All instances of rates more than three times the current trend were associated with index values above this threshold.

In Suva, however, while a clear trend is evident of increasing risk of diarrhoea with increasing risk index, there is ambiguity surrounding a suitable threshold (or early warning system "trigger"). All months where the ratio of incidence to trend exceeded 3 had positive risk index ($DRI > 0$) (see Figure 7). However, if warnings are issued whenever $DRI > 0$, based on historical patterns, a majority of warning events will be followed by near normal diarrhoea rates. It would likely therefore prove difficult to define a threshold level of risk for diarrhoeal disease in Suva with sufficient specificity (i.e. avoiding false positives). A proposed mechanism for such an EWS is outlined in Figure 8.

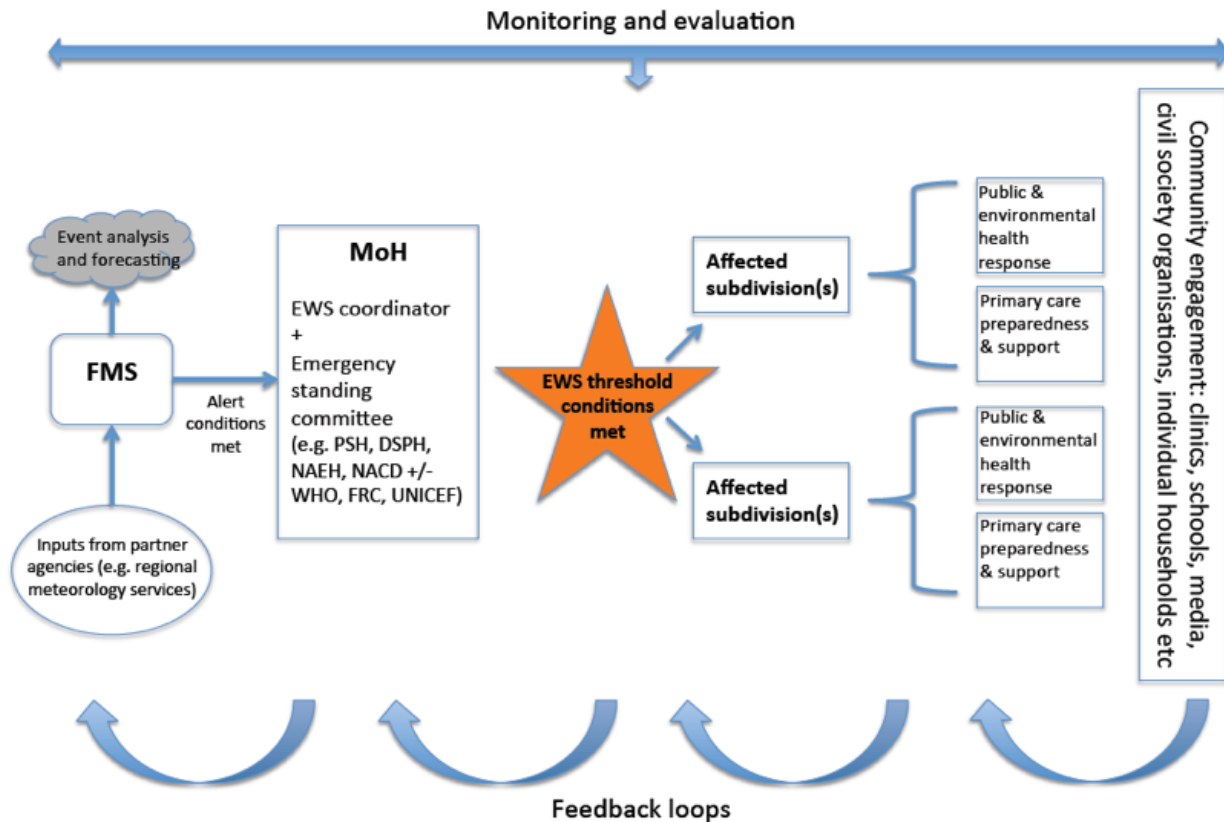


Figure 8. Hypothetical climate-based early warning system for Fiji

NB. "Abbreviations in Figure 8 -" FMS: Fiji Meteorology Service; MoH: Ministry of Health; PSH: Permanent Secretary for Health; DSPH: Deputy Secretary for Public Health; NAEH: National Advisor for Environmental Health; NACD: National Advisor for Communicable Diseases; WHO: World Health Organization; FRC: Fiji Red Cross; UNICEF: United Nations Children's Fund; EWS: Early warning system.

If the meteorological identification and forecasting components may be assumed to be sufficiently accurate and timely, the next questions are whether or not the forecast can be communicated effectively to the target community, and whether or not effective responses are feasible. Caution must thus be advised when considering such EWSs as health sector-led strategies in developing country settings such as Fiji where, typically, the health system is already at or approaching maximum capacity. Following the flooding disasters in Fiji in early 2012, public and environmental health staff in one of the most affected subdivisions commented that an EWS would be of little or no practical value if adequate/increased resourcing was not also provided to enable the intervention.

It must also be recognised that EWSs based on the models above must take into account the potential sources of error and bias of this study. This include, but are not limited to, systematic errors in data collection, reporting and analysis; intrinsic differences in data validity and/or public health practice between the two study sites; and the inability of the models above to incorporate non-climate factors contributing to disease activity. Future lines of inquiry relevant to this work could, inter alia, include finer spatiotemporal analysis and ecological testing of microbial contamination of water supplies, and the socio-environmental contributors to this process.

At the most basic level, an operationally effective EWS might be achieved by the improved communication of existing weather or climate forecasts to a community that is already willing and able to take appropriate action.

In the case of diarrhoeal disease, such actions may range from temporary relocation to avoid a storm surge, to intensive health promotion campaigns (e.g. targeting household water, sanitation and hygiene measures to reduce the risk of diarrhoea), in addition to alerting health professionals of the likelihood of increased presentations during periods of increased risk.

The evaluation of such systems is, of course, critical to their viability and effectiveness. Along with cost-benefit analyses, a fundamental process is that of information feedback. An "iterative management" approach, which uses monitoring and evaluation to incorporate information feedback to improve the efficiency and effectiveness of such initiatives as an EWS, would be necessary to enhance, over time, the accuracy – in terms of both sensitivity and specificity - of the mechanism (Ebi, 2014). There is also an emerging body of work related to the statistical evaluation of EWS models (Chaves & Pascual, 2007).

With respect to the generalizability of climate-based EWSs as potential climate change and health adaptation measures for other climate-sensitive diseases in Fiji, and comparable risks in other Pacific island countries, it is suggested that EWS development should be attempted initially for the most important health risks. Weighing up the relative importance of different climate risks to health is a difficult task. This is the case even under a steady-state assumption, but even more so if the past is seen to be an unreliable guide to the future, given climate change trends. It is beyond the scope of the present guide to provide detailed advice on this aspect, however, such guidance is available elsewhere (Lindgren et al., 2012).

In many cases, the groundwork will have been done as part of a vulnerability and adaptation assessment, in which case these established priorities should be the starting point for EWS development, as was the case for this project in Fiji.

It is not possible to be definitive in a general sense about the appropriate priority for EWS in the wider context of policy responses to climate change, since such decisions will depend upon local circumstances, and the priority climate-sensitive health risks. Thus a “horses for courses” approach is recommended for climate and health modelling, such as that required for EWS mechanisms (Ebi & Rocklov, 2014).

It is also clear that EWSs should not be seen as a stand-alone response to climate-health risks, but as part of a comprehensive policy response, which combines adaptation measures with, inter alia, mitigation, promotion of health co-benefits and improvements in health systems efficiency and resilience. Integration of EWSs into other, broader primary health care and public health surveillance and response systems will be vital to optimise their effectiveness (Grasso et al., 2012). In Fiji, such integration may be possible in the context of disaster preparedness and response; infectious disease surveillance; food and water safety testing; and the emergency capacity-building activities of bodies such as the Pacific Humanitarian Team. Other opportunities for integration include the potential to use existing meteorological forecast systems, such as the seasonal forecasts provided by the FMS for the agriculture sector, in application to specific disease models (e.g. providing a three month ‘diarrhoea risk outlook’ for the wet season in Fiji).

It is pertinent to note that, in Pacific SIDS, including Fiji, there are many challenges involved in devising and implementing such EWSs as adaptation strategies. These challenges include, but are not limited to, the incompleteness and variable accuracy of both climate and disease datasets; the geographic remoteness of many islands and/or communities; and the lack of physical, human and financial resources for additional health sector activities.

Nevertheless, Fiji and other Pacific island countries also have some inherent advantages which could, theoretically, enable such systems. Such advantages relate primarily to social networks within small populations, whereby information can be relatively easily transmitted between actors and agencies, given the often close ties between individuals and communities. This combination of “bonding” and “bridging” types of social capital which have emerged from the nascent literature on climate change and health governance (Bowen et al., 2014; Bowen et al., 2013) may prove to be particularly relevant in the Pacific.

Such social capital could also be considered to extend across the Pacific region, giving rise to the possibility of a regional network integrating meteorological and environmental determinants of infectious disease risk, along with demographic, socioeconomic and spatial factors, to provide a more comprehensive understanding of the epidemiology of health risks in the region. A potentially very useful example of such multi-disciplinary, trans-border collaboration along these lines is the European Environment and Epidemiology Network*

Conclusion

EWSs such as that proposed for diarrhoeal disease in these pilot sites in Fiji appear to be a promising adjunct to contemporary public health practice, and a potentially useful innovation in the context of climate change and health adaptation. The analysis described in this paper suggests that an index of diarrhoea risk could be used to determine appropriate thresholds to trigger proactive public health actions aimed at reducing the impact of diarrhoeal disease in Fiji.

* (<https://e3geoportal.ecdc.europa.eu/SitePages/General%20Description.aspx>).

While recognising that these are potentially powerful tools to reduce the current and future burden of disease due to climate variability and change, EWSs must nevertheless be employed sparingly and accurately. *To paraphrase eighteenth century French philosopher Montesquieu: “Useless warnings weaken necessary warnings”.*

Finally, it must be remembered that, in the long term, the most cost-effective response to climate change, including in relation to its detrimental effects on human health, is likely to be mitigation – reducing global greenhouse gas emissions to protect the health of our population and planet.

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References

- Basher, R. (2006). *Global early warning systems for natural hazards: systematic and people-centred. Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences*, 364(1845), 2167–82. doi:10.1098/rsta.2006.1819
- Bouzid, M., Colón-González, F. J., Lung, T., Lake, I. R., & Hunter, P. R. (2014). *Climate change and the emergence of vector-borne diseases in Europe: case study of dengue fever. BMC Public Health*, 14(1), 781. doi:10.1186/1471-2458-14-781
- Bowen, K., Alexander, D., Miller, F., & Dany, V. (2014). *Using Social Network Analysis to Evaluate Health-Related Adaptation Decision-Making in Cambodia. International Journal of Environmental Research and Public Health*, 11(2), 1605–1625. doi:10.3390/ijerph110201605
- Bowen, K., Ebi, K., Friel, S., & McMichael, A. (2013). *A multi-layered governance framework for incorporating social science insights into adapting to the health impacts of climate change. Global Health Action*, 1, 1–6. Retrieved from <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3772341/>
- Chaves, L. F., & Pascual, M. (2007). *Comparing models for early warning systems of neglected tropical diseases. PLoS Neglected Tropical Diseases*, 1(1), e33. doi:10.1371/journal.pntd.0000033
- Chowell, G., Cazelles, B., Broutin, H., & Munayco, C. V. (2011). *The influence of geographic and climate factors on the timing of dengue epidemics in Perú, 1994–2008. BMC infectious diseases (Vol. 11, p. 164)*. doi:10.1186/1471-2334-11-164
- Connor, S. J., Omumbo, J., Green, C., DaSilva, J., Mantilla, G., Delacollette, C., ... Thomson, M. (2010). *Health and Climate – Needs. Procedia Environmental Sciences*, 1, 27–36. doi:10.1016/j.proenv.2010.09.004
- Descloux, E., Mangeas, M., Menkes, C. E., Lengaigne, M., Leroy, A., Tehei, T., ... De Lamballerie, X. (2012). *Climate-based models for understanding and forecasting dengue epidemics. PLoS Neglected Tropical Diseases*, 6(2), e1470. doi:10.1371/journal.pntd.0001470
- Ebi, K. L. (2014). *National and Global Monitoring and Surveillance Systems for the Health Risks of Global Change*, 649–655. doi:10.1007/978-94-007-5784-4
- Ebi, K. L., Lewis, N. D., Corvalan, C., & Lucia, S. (2006). *Climate Variability and Change and Their Potential Health Effects in Small Island States : Information for Adaptation Planning in the Health Sector. Environmental Health Perspectives*, 114(12), 1957–1963. doi:10.1289/ehp.8429

- Ebi, K. L., & Schmier, J. K. (2005). A stitch in time: improving public health early warning systems for extreme weather events. *Epidemiologic Reviews*, 27, 115–21. doi:10.1093/epirev/mxi006
- Ebi, K., & Rocklöv, J. (2014). Climate change and health modeling: horses for courses. *Global Health Action*, 1, 1–5. Retrieved from <http://www.globalhealthaction.net/index.php/gha/article/view/24154>
- Falagas, M. E., Bliziotis, I. a, Kosmidis, J., & Daikos, G. K. (2010). Unusual climatic conditions and infectious diseases: observations made by Hippocrates. *Enfermedades Infecciosas Y Microbiología Clínica*, 28(10), 716–8. doi:10.1016/j.eimc.2009.11.013
- Grasso, M., Manera, M., Chiabai, A., & Markandya, A. (2012). The health effects of climate change: a survey of recent quantitative research. *International Journal of Environmental Research and Public Health*, 9(5), 1523–47. doi:10.3390/ijerph9051523
- Hashizume, M., Armstrong, B., Hajat, S., Wagatsuma, Y., Faruque, A. S. G., Hayashi, T., & Sack, D. a. (2007). Association between climate variability and hospital visits for non-cholera diarrhoea in Bangladesh: effects and vulnerable groups. *International Journal of Epidemiology*, 36(5), 1030–7. doi:10.1093/ijed/dym148
- Hii, Y. L., Zhu, H., Ng, N., Ng, L. C., & Rocklöv, J. (2012). Forecast of Dengue Incidence Using Temperature and Rainfall. *PLoS Neglected Tropical Diseases*, 6(11), e1908. doi:10.1371/journal.pntd.0001908
- Huang, C., Barnett, A., & Xu, Z. (2013). Managing the Health Effects of Temperature in Response to Climate Change: challenges ahead. *Environmental Health Perspectives*, (4), 415–419. Retrieved from <http://ehp.niehs.nih.gov/pdf-files/2013/feb/ehp.1206025.pdf>
- Hunter, P. R. (2003). Climate change and waterborne and vector-borne disease. *Journal of Applied Microbiology*, 94 Suppl, 37S–46S. Retrieved from <http://www.ncbi.nlm.nih.gov/pubmed/12675935>
- IFRC. (2012). Community early warning systems: guiding principles. <http://www.ifrc.org/PageFiles/103323/1227800-IFRC-CEWS-Guiding-Principles-EN.pdf>
- Intergovernment Panel on Climate Change (IPCC), Working Group II, Fifth Assessment Report (2014). WGII AR5 Glossary, (October 2013), 1–30.
- Kuhn, K., Campbell-lendrum, D., Haines, A., & Cox, J. (2005). Using climate to predict infectious disease epidemics. WHO.
- Lindgren, E., Andersson, Y., Suk, J. E., Sudre, B., & Semenza, J. C. (2012). Monitoring EU emerging infectious disease risk due to climate change. *Science (New York, N.Y.)*, 336(6080), 418–9. doi:10.1126/science.1215735
- McIver, L., Naicker, J., Hales, S., Singh, S., Dawainavesi, A. (2012). Climate change and health in Fiji: environmental epidemiology of infectious diseases and potential for climate-based early warning systems. *Fiji Journal of Public Health*, 1(1):7-13
- McIver, L., Woodward, A., Davies, S., Tibwe, T., & Iddings, S. (2014). Assessment of the Health Impacts of Climate Change in Kiribati. *International Journal of Environmental Research and Public Health*, 1–17. doi:10.3390/ijerph110x0000x
- 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), 155–9. Retrieved from <http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1240636&tool=pmcentrez&rendertype=abstract>
- Secretariat of the Pacific Regional Environment Programme. (2013). JNAP development and implementation in the Pacific: experiences, lessons and way forward. <http://www.sprep.org/publications/jnap-development-and-implementation-in-the-pacific-experiences-lessons-and-way-forward>
- Thomson, M. C., Doblaz-Reyes, F. J., Mason, S. J., Hagedorn, R., Connor, S. J., Phindela, T., ... Palmer, T. N. (2006). Malaria early warnings based on seasonal climate forecasts from multi-model ensembles. *Nature*, 439(7076), 576–9. doi:10.1038/nature04503
- Weinberger, D., Baroux, N., Grangeon, J.-P., Ko, A. I., & Goarant, C. (2014). El niño southern oscillation and leptospirosis outbreaks in new caledonia. *PLoS Neglected Tropical Diseases*, 8(4), e2798. doi:10.1371/journal.pntd.0002798
- WHO. (2003). Climate change and human health: risks and responses. World Health. Retrieved from http://books.google.com/books?hl=en&lr=&id=tQFYjJDEwhIC&oi=fnd&pg=PP11&dq=Climate+change+and+human+health:+risks+and+responses&ots=PqBuXRW_f&sig=jrvKgQTqbUsP-JfDEejVLOHvgVQ
- World Health Organization and World Meteorological Organization (2012). Atlas of Health and Climate. Retrieved from <http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Atlas+of+Health+and+Climate#5>
- Wu, J., Yunus, M., Sreatfield, P. K., & Emch, M. (2013). Association of climate variability and childhood diarrhoeal disease in rural Bangladesh, 2000–2006. *Epidemiology and Infection*, 1–10. doi:10.1017/S095026881300277X
- Yu, W., Mengersen, K., Dale, P., Ye, X., Guo, Y., Turner, L., ... Tong, S. (2014). Projecting future transmission of malaria under climate change scenarios: Challenges and research needs. *Critical Reviews in Environmental Science and Technology*, (March 2014), 140225123945003. doi:10.1080/10643389.2013.852392

Chapter Ten

Paper 7: Climate change, overcrowding and non-communicable diseases: the “triple whammy” of tuberculosis transmission risk in Pacific atoll countries

Prelude

In this chapter, a case study of the Pacific region’s three independent, exclusively-atoll countries is described, whereby extreme climate change vulnerability – particularly in the form of sea-level rise – is combining with accelerating rates of non-communicable diseases and population growth, to create an unprecedented cocktail of communicable disease transmission risk factors. The paper explores this convergence of risk with reference to tuberculosis (TB), and argues that, in this context at least, this important disease of profound global concern should be added to the list of those considered “climate-sensitive”.

The three countries in question – Kiribati, Marshall Islands and Tuvalu – have the highest rates of TB in the Pacific, and among the highest in the world. These three low-lying atoll nations also have alarmingly high rates of non-communicable diseases such as diabetes and health risk behaviors such as smoking, which are additional drivers of TB transmission risk. When added to the population pressures within these land- and resource-poor atolls, where high fertility rates and severe overcrowding are being exacerbated by sea-level rise and storm surges, leading to forced relocation, it is argued in this chapter that these factors constitute a “triple whammy” of TB transmission risk in some Pacific atoll communities.

The candidate’s estimated proportional contributions to this paper were as follows:

Research design:	80%
Analysis and interpretation:	70%
Authorship of paper:	60%

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CLIMATE CHANGE, OVERCROWDING AND NON-COMMUNICABLE DISEASES: THE 'TRIPLE WHAMMY' OF TUBERCULOSIS TRANSMISSION RISK IN PACIFIC ATOLL COUNTRIES

Lachlan McIver,^{1,2} Kerri Viney,² David Harley,² Liz Hanna,² Takeieta Kienene³

1. College of Public Health, Medical and Veterinary Sciences, James Cook University, Townsville, Queensland, Australia

2. National Centre for Epidemiology and Population Health, Research School of Population Health, Australian National University, Canberra, ACT, Australia

3. Kiribati National Tuberculosis Programme, Ministry of Health and Medical Services, Government of Kiribati, Tarawa, Kiribati

Abstract

The atoll nations of Kiribati, Marshall Islands and Tuvalu are home to the highest rates of tuberculosis in the Pacific region. These countries also have very high rates of poverty, overcrowding and non-communicable diseases such as smoking and diabetes mellitus, which are all well-established risk factors for tuberculosis transmission. In addition, these three countries are among the most vulnerable in the world to the impacts of climate change, due to, *inter alia*, their very low elevation and extreme susceptibility to sea-level rise and extreme weather events such as cyclones, droughts and storm surges. Tuberculosis transmission rates have been linked to climate activity, such as changing seasons, yet tuberculosis has not hitherto been seriously discussed in the international literature as an infectious disease considered susceptible to climate change. This paper highlights the unique and unprecedented convergence of social and environmental risk factors for tuberculosis transmission risk in these three Pacific atoll countries, which demonstrate that tuberculosis is indeed a 'climate-sensitive' disease warranting international support for climate policy and public health intervention.

Key words: Pacific Islands, climate change, tuberculosis, non-communicable diseases

Introduction

The small island developing states (SIDS) of the Pacific region are among the most vulnerable in the world to the impacts of climate change, including the likely detrimental effects on human health.¹⁻⁴ The pathways by which climate change threatens population health may be considered in terms of direct (or primary), indirect (or secondary) and disseminated, diffuse or tertiary effects.⁵⁻⁷ The priority 'climate-sensitive' health risks identified by Pacific island countries (PICs) in the vulnerability and adaptation assessment process led by the World Health Organization (WHO) between 2010 and 2013 include such direct effects (e.g. health impacts of extreme weather events and heat-related illnesses); indirect effects (including compromised water and food security and safety, and increasing burden of water- and food-borne diseases; increasing incidence of vector-borne diseases, zoonoses and respiratory illnesses; and disorders of the eyes, ears, skin and other body systems); and diffuse effects (disorders of mental/psychosocial health; increasing burden of non-communicable diseases; health system problems and population pressures).^{8,9} Climate-sensitive health risks for PICs correspond largely with risks reported for other geographical areas.¹⁰⁻¹³ In the Pacific, however, there exists a contemporary confluence of demographic, socio-economic and environmental risk factors that highlights some specific diseases hitherto overlooked in the climate change and health literature. One of these diseases is tuberculosis (TB) – a scourge since ancient times, still present in many developing countries, including the extremely climate-sensitive Pacific atoll nations of Kiribati, Marshall Islands and Tuvalu, where the prevalence of TB is among the highest in the world.¹⁴

TB is a mycobacterial infection spread by respiratory droplets. Recent progress in case detection, diagnostics, treatment and follow-up care notwithstanding, TB is still responsible for approximately 8.6 million new infections and 1.3 million deaths annually worldwide.^{15,16} TB transmission risk is linked to conditions favouring exposure to infected individuals (e.g. poverty, overcrowding)^{17,18} and impairment of the immune response of exposed individuals (e.g. HIV infection, alcohol abuse, malnutrition and immunosuppressive drugs).¹⁹ Diabetes mellitus also compromises immune function, and is thus associated with increased TB infection and mortality.^{20,21} Smoking and indoor air pollution are significant additional TB risk factors.²² Risk factors for TB have been studied in depth in the relevant literature. One of the more holistic models of transmission considers population-wide determinants such as globalisation, urbanisation, poverty, and weak social, economic and environmental policies; and 'proximate' risk factors that affect individuals, such as malnutrition, HIV infection, lung diseases, diabetes mellitus and smoking.^{18,23} The roles of the physical environment

and meteorological factors, and the potential impact of climate change on TB transmission have been surprisingly absent from much of this literature. Despite Hippocrates of Cos – often referred to as the 'Father of Medicine' – having noted the relationship between variations in climate and patterns of disease, including 'phthisis' (TB) over two millennia ago,²⁴ and century-old reports discussing the impact of different types of climate on recovery of patients with TB,²⁵⁻²⁷ specific consideration of the seasonality and climate-sensitivity of TB seems only to have returned to serious consideration relatively recently.²⁸⁻³¹ Given this correlation between climatic factors and TB activity, it seems reasonable to assume that globalization and the manifestations of climate change, in particular the prospect of more frequent and/or severe environmental disasters, may increase TB transmission risk, primarily by increasing the exposure of infectious individuals to others,^{32,33} or via interplay with established risk factors such as HIV.³⁴

This paper explores some important environmental and social determinants of TB transmission risk, that are considered in relation to the case study of three low-lying atoll countries in the Pacific region: Kiribati, Marshall Islands and Tuvalu. In doing so, well-understood TB risk factors such as overcrowding and smoking are placed in the context of 21st century health and development challenges facing Pacific communities, most particularly the effects of climate change and the 'epidemic' of non-communicable diseases (NCDs).³⁵ We postulate that a convergence of established and novel risk factors is occurring that may increase TB transmission risk for these island nations, if appropriate adaptation and mitigation strategies and socio-economic policies for poverty reduction are not implemented promptly and effectively.

Methods

We performed a retrospective descriptive analysis of secondary data from the three study countries related to TB infection rates, the prevalence of diabetes and other NCD risk factors, and population, demographic and geopolitical information relevant to climate change. The primary sources of this information were census and survey data from each country, as well as the Demographic and Health Surveys conducted by the Secretariat for the Pacific Community (SPC, the regional technical agency based in New Caledonia) and the WHO STEPwise Surveillance of NCD Risk Factors (STEPS) surveys. In addition, the available literature on the epidemiology and social and environmental determinants of TB was reviewed, to assess the possible impact of converging risk factor pathways on TB transmission risk in the three study countries. Finally, a conceptual model was developed, drawing upon aspects of earlier models,¹⁸ to explain this unique convergence of TB risk factors occurring in the Pacific atoll context.

Results

The table presents the descriptive analysis of the key risk factors related to TB and climate change impacts in the three Pacific atoll study countries.

Indicator	Kiribati	Tuvalu	Marshall Islands	Data source
Burden of TB				
TB Prevalence (/100 000)	628 (10th highest in world)	377 (31st highest in world)	1080 (2nd highest in world)	2012 TB data taken from the WHO Global Tuberculosis Report 2013 (WHO, 2013a)
Incidence (/100 000)	429	241	572	
Case notifications (/100 000)	343 (1st in Pacific)	193 (4th in Pacific)	276 (3rd in Pacific)	
Mortality (/100 000)	17	37	111	
Population size				
Population (2011 estimates unless otherwise stated)	103,758 (2010)	11,206	54,999	Kiribati: Kiribati Census of Population and Housing (Government of Kiribati, 2011) Marshall Islands, Tuvalu: SPC-Statistics for Development Division 2011
Proportion living in urban settings	49%	47%	65%	
Upstream determinants				
Population density (persons/square kilometre)	127 (national) (80th in world) 3184 (South Tarawa in 2010)	431 (national)(30th in world) 1900 (Funafuti in 2002)	304 (national)(44th in world) 2619 (Majuro in 2008) ~ 41,700 (Ebeye in 2011)	Kiribati: Current pop. density: Kiribati census 2005. Projected pop. density SPC-Statistics for Development Division 2011 Tuvalu: SPC-Statistics for Development Division 2011 Marshall Islands: SPC-Statistics for Development Division 2011
Projected population density (national average persons/square kilometre, by 2030)	170	480	345	
Annual net population growth rate	1.8%	0.5%	0.7%	SPC- Statistics for Development Division1
Gross Domestic Product per capita in USD	2,907	7,103	3,327	SPC- National Minimum Development Indicators2
Basic needs poverty rate*	21.8	26.3	52.7	SPC- National Minimum Development Indicators2
Youth literacy (%)	98.5%	98.6%	98%	SPC- National Minimum Development Indicators2
Proximate risk factors				
Diabetes mellitus in adults aged 20-79 Prevalence (year)	28.77% (2013)	14.53% (2013)	34.89% (2013)	International Diabetes Federation Diabetes Atlas, Sixth Edition (IDF, 2013)
TB-diabetes co-incidence (Specific location, where specified)	37%	9.5%	45% (Ebeye)	Kiribati: CDC-SPC-MHMS study (Viney et al, unpublished data) Tuvalu: Personal communication- Ms Temilo Seono (National TB Programme Co-ordinator) Marshall Islands: Nasa et al, 2014
Prevalence of overweight and obesity in adults (aged 15-64 years)	Males: 41.7% Females: 58.9%	Males: 76.3% Females: 87.9% ("overweight or obese")	Males: 37.9% Females: 52.2%	Kiribati and Marshall Islands: PICT NCD Risk Factor STEPS reports, 2005-2010 Tuvalu: Tuvalu DHS 2007
Smoking rates (Proportion adults who are daily smokers, aged 15 years and above)	54.8% (males 71.5%, females 39.2%)	37.9% (males 54.6%, females 22.7%)	19.8% (males 34.7%, females 4.2%)	Kiribati: WHO 2011 (from Kiribati STEPS, 2006) Tuvalu: WHO 2011 (from Tuvalu census 2002) Marshall Islands: WHO 2011 (from RMI STEPS 2002)
Prevalence of HIV infection Incident HIV diagnoses (2011)	0.018 2	0.052 0	0.030 1	SPC HIV epidemiological update 2012
Total fertility rate (births/woman) Crude birth rate (/1000 population)	Urban 3.5 Rural 4.1 Urban 30.7 Rural 28.8	Urban 4.2 Rural 3.7 22.9	Urban 4.1 Rural 5.2 31.1	Kiribati: SPC Kiribati DHS 2009 Tuvalu: TFR from Tuvalu DHS 2007, CBR from Tuvalu census 2002 Marshall Islands: TFR from RMI DHS 2007, CBR from SPC-Statistics for Development Division 2011 (last census 1999)
Household composition (i.e. level of overcrowding) Average number of people/household Proportion of households with ≥9 people	Urban 7.3 Rural 5.3 Urban 30% Rural 11%	Urban (Funafuti) 6.2 Rural (outer islands) 5.8 Funafuti: 31% Outer islands 6%	Urban 7.6 Rural 6.6 Urban >30% Rural ~25%	Kiribati: SPC Kiribati DHS 2009 Tuvalu: Tuvalu DHS 2007 Marshall Islands: RMI DHS 2007
Use of solid fuel for cooking (at household level) Use of stove/fire with no chimney/hood (as proportion of all households using solid fuel)	68.8% 98.2%	21.0% 77.9%	36.3% 93.7%	Kiribati: Kiribati DHS 2009 Tuvalu: Tuvalu DHS 2007 Marshall Islands: RMI DHS 2007
Environmental				
Maximum elevation (in metres)	81 (Banaba) (231st in world); majority of inhabited atolls <3	5 (243rd in world)	10 (242nd in world)	www.wikipedia.com

1. <http://www.spc.int/sdd/>

2. <http://www.spc.int/nmdi/>

*The proportion of the population living in poverty (as defined by the Millennium Development Goals (<http://www.un.org/millenniumgoals/poverty.shtml>))

As can be seen from the table, Kiribati, Marshall Islands and Tuvalu are relatively poor, extremely low-lying, urbanized and population-dense countries, meaning that the manifestations of climate change, particularly sea-level rise, are having – and will continue to have – profound effects on their respective societies and economies. These three countries have among the highest prevalence rates of TB and diabetes mellitus in the world. Between 15 and 35% of the adult population in these countries have diabetes, and up to 45% of TB patients have concomitant diabetes, which is of great concern in these countries experiencing the ‘triple burden’ of NCDs, communicable

diseases and climate change.^{36,37} A number of other social and environmental risk factors for TB are summarised in the table. The very high population densities of each country’s capital atoll (South Tarawa in Kiribati, Majuro in the Marshall Islands and Funafuti in Tuvalu) and the extreme levels of overcrowding on Ebeye island in the Marshall Islands warrant special attention. An examination of these multiple, convergent risk factors in the three study countries suggests that there are plausible pathways by which climate change may interact with other, established TB risk factors and consequently act as an indirect driver of TB transmission risk (Figure 1).

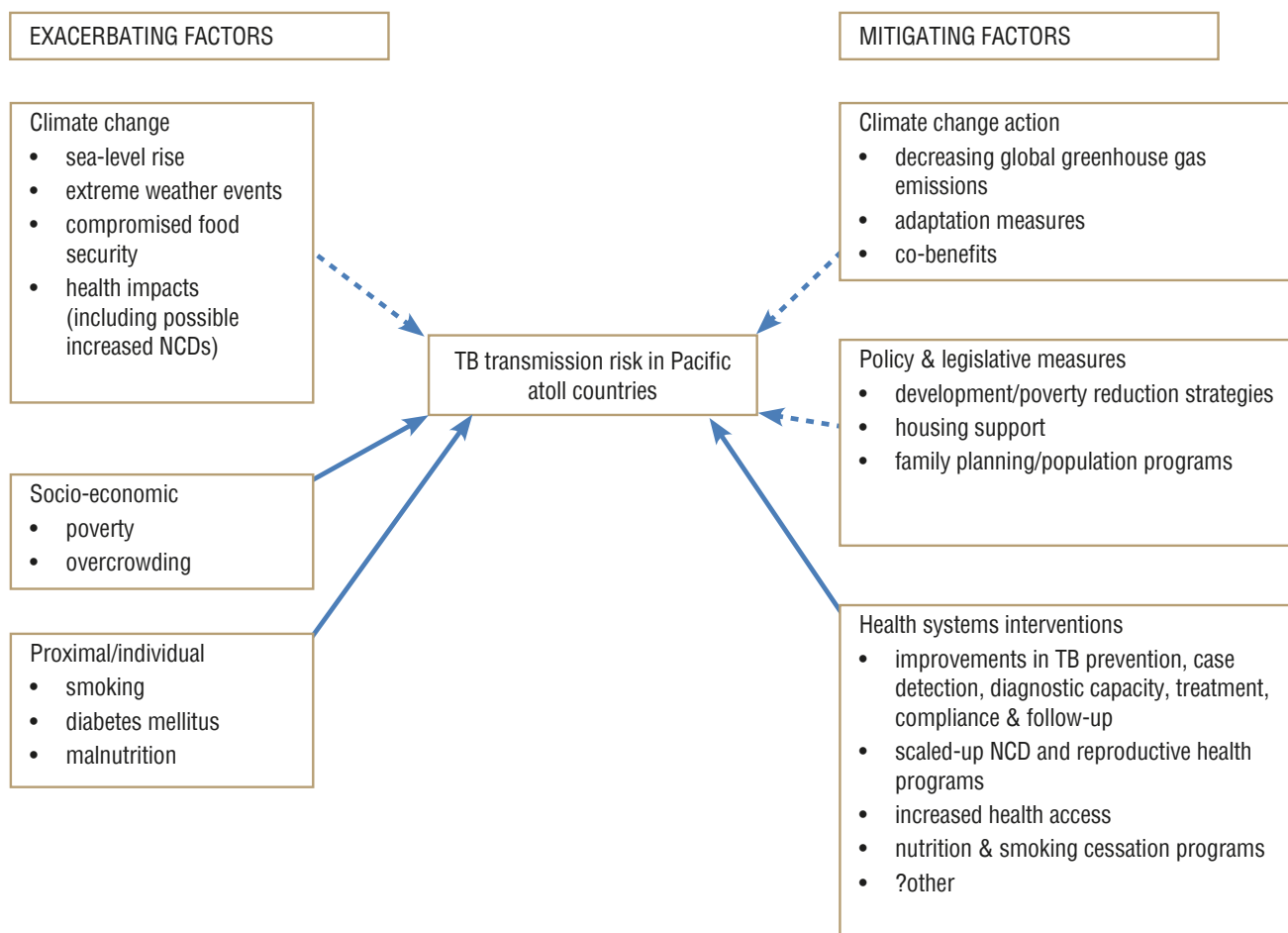


Figure 1. Schematic representation of risk factors for tuberculosis transmission in Pacific atoll countries and opportunities for intervention (NB. solid lines indicate where current research supports links; dashed lines indicate new/hypothetical links)

Discussion

Pacific island atoll countries such as Kiribati, Marshall Islands and Tuvalu have very high burdens of both TB itself, and some of the critical risk factors – such as overcrowding and NCDs – that contribute to TB transmission. TB rates have remained high in all three countries over time, despite increased investment in disease prevention and control, improved management, active TB case-finding strategies and highly sensitive and specific diagnostic tools.³⁸ All three countries of these countries are also extremely vulnerable to the biopsychosocial effects of climate change. These effects potentially amplify the role of TB determinants and risk factors through environmental, economic and social pathways (Figure 1). Thus, Kiribati, Marshall Islands and Tuvalu are likely unique in the Pacific - and possibly global - context, in sharing environmental and social characteristics that potentially increase the risk of TB, not to mention other infectious diseases, due to climate change-related phenomena such as sea-level rise. A few of the most important of these converging TB risk factors will be discussed in more detail below in relation to the three study countries.

Poverty

Poverty increases the risk of TB infection and worsens an individual’s prognosis.^{39,40} Evidence for this is suggested in the Pacific, where high rates of TB are observed in atoll countries with lower per capita income levels (Table). Conversely, the largest reductions in the burdens of TB over recent decades have been achieved in two PICs (Commonwealth of the Northern Mariana Islands and New Caledonia) which are both classified as high-income countries and whose level of economic development has ensured a better standard of living - including access to health care - across all income groups.

Overcrowding

Another significant concern in relation to TB risk is overcrowding. Urbanised areas in the capital atolls of each country (respectively, South Tarawa, Majuro and Funafuti) are becoming increasingly crowded. This has been identified as a significant risk factor for TB transmission, both in terms of overall population density⁴¹ and household-level overcrowding,⁴² whereby the number of persons per room is strongly associated with TB transmission risk.⁴³

Population growth

High fertility rates compound the problem of population density and household-level overcrowding in all three countries.^{44,45} To ensure sustainable development in Kiribati, Marshall Islands and Tuvalu, population growth must slow. This is especially important in the context of rural-urban migration and climate change, which increase both demand for and availability of land.⁴⁶ In parallel, measures targeting women's education and family planning must be implemented in parallel with economic development, and improved housing and infrastructure. All of these may be considered to be intrinsic – or at least related – to climate change adaptation. There has been significant attention, and some action to date, on adaptation in the Pacific, and in Kiribati in particular. One such adaptation measure, which is relatively extreme but deemed necessary by the leadership within the government of Kiribati, is the re-location of *i-Kiribati* citizens to neighbouring islands or countries, as one measure to reduce population density in South Tarawa (Anoté Tong, President of Kiribati, personal communication, 2013).

Smoking and diabetes

Smoking and diabetes are important proximate risk factors for TB in the Pacific context; smoking is also a well-known risk factor for a range of other NCDs including heart disease and certain cancers.^{47,48} Smoking and diabetes increase the risk of TB synergistically^{20,22} and approximately 29% of all TB in 22 high-burden endemic countries is attributable to these two proximate risk factors.¹⁸ Seven of the ten highest diabetes-prevalence countries globally are in the Pacific, with Marshall Islands and Kiribati respectively the third and fourth highest.⁴⁹ Both countries are implementing TB-diabetes collaborative control activities in response to the identified link between the two diseases, with patients with diabetes recognised as having a threefold risk of developing TB.^{20,50,51} Case-control studies conducted in Kiribati show that TB patients appear three times more likely to have diabetes than people without TB (Viney *et al*, unpublished data, 2014) and in the Marshall Islands approximately 45% of TB patients had concomitant diabetes (Nasa *et al*, 2014). Global efforts to detect, diagnose and control diabetes are therefore likely to have a positive impact on TB control.^{52,53} All three study countries also have high rates of daily cigarette smoking – see table. Thus, localised strategies to prevent and reduce the burden of diabetes and smoking appear likely to reduce the burden of TB in the Pacific.

Climate change

These three low-lying atoll countries are among the most vulnerable in the world to the impacts of, *inter alia*, sea-level rise (bringing with it the prospect of forced relocation) and the potential for compromised water and food security. Food security – which exists 'when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life' – is a complex development issue which has already had a profound negative impact on the health of Pacific island populations.⁵⁴ Compromised food security can result in over-nutrition, with resultant increase in individual and population level overweight and obesity, and subsequent development of type 2 diabetes.⁵⁵ The fragility of food security is compounded in atolls due to the lack of arable land for agriculture and the related scarcity of fresh water.⁵⁶ Water, sanitation and hygiene (WASH) problems already place a heavy burden on *i-Kiribati* communities, as the absence of groundwater sources enforces a reliance on rainwater harvesting and wells to aquifers, which frequently become contaminated with pathogens causing diarrhoea.⁵⁷ This, along with the lack of improved sanitation facilities in most households and the common practice of open defecation (including in the lagoon side of the atolls), particularly in children, contributes to high rates of diarrhoeal disease, which then feeds into a vicious cycle of malnutrition, immune suppression and increased transmission of infections.⁵⁸ There is little research on the association of TB and climate change, and TB has been hitherto all but absent from the various published lists of diseases thought likely to be susceptible to climate change. We argue that traditional schemas for upstream determinants and risk factors for TB should incorporate the wider effects of climate change and consideration of the ecology of fragile island environments. These islands have a unique suite of vulnerabilities which impacts on the health of their populations, but may also provide

opportunities for intervention. The latter mainly relate to interventions to reduce poverty, smoking and NCD rates, as well as reducing greenhouse gas emissions and enabling the so-called 'co-benefits' of climate change mitigation, which have positive effects on individual and population health.

Other opportunities for health protection include mainstreaming climate change adaptation and mitigation measures with health systems strengthening. Guidelines exist on building climate-resilient health systems, which incorporates the full spectrum of health sector activities, from research, governance, financing, emergency preparedness and capacity-building to provision of essential services, technology and infrastructure.⁵⁹ Poorly-resourced health systems such as those in Kiribati, Marshall Islands and Tuvalu are at close to maximal capacity at present, yet still struggle to achieve adequate health access and outcomes. These difficulties are very likely to be exacerbated by climate change, as with other major development challenges, thus any support to the health sector in these and other countries facing similar challenges may be considered not just relevant, but vital to climate change adaptation.

Conclusion

In the Pacific atoll countries of Kiribati, Marshall Islands and Tuvalu there is a unique convergence of risk factors for TB that is coupled with the already devastating effects of climate change in these highly vulnerable communities. Therefore, we argue that, in the Pacific atoll context at least, TB must be considered a climate-sensitive disease. Efforts towards addressing the causes and effects of climate change in these small, poor, overcrowded, low-lying atoll countries must take into account the broad range of health impacts that climate change entails, and the health sector should provide leadership in addressing these impacts via a 'Health in all policies' approach to adaptation and mitigation. In addition, efforts towards improved TB control should incorporate wider contextual issues such as social, economic and environmental factors driving disease transmission, and consider the unprecedented pressures that climate change places on TB and other, hitherto overlooked, climate-sensitive diseases. Policies and interventions to improve the socioeconomic status of communities (including poverty reduction strategies and provision of adequate housing); increasing access to, and quality of, health services (particularly those related to TB, NCDs and reproductive health); and addressing the drivers and impacts of climate change, will benefit population health, and have the potential to reduce TB transmission risk in the face of climate change in Pacific atolls and other vulnerable communities elsewhere in the developing world.

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References

1. Pachauri RK, Allen MR, Barros VR, Broome J, Cramer W, Christ R, *et al*. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Available at: <http://epic.awi.de/37530/> (accessed 28 October 2015)
2. Mimura N. Vulnerability of island countries in the South Pacific to sea level rise and climate change. *Clim Res* 1999; 12: 137-43.
3. Russell L. Poverty, climate change and health in Pacific island countries. Menzies Centre for Health Policy, 2011. Available at: <http://ses.library.usyd.edu.au/handle/2123/9202> (accessed 28 October 2015)
4. Woodward A, Hales S, Weinstein P. Climate change and human health in the Asia Pacific region: who will be most vulnerable? *Clim Res* 1998; 11: 31-8.
5. Butler CD, Harley D. Primary, secondary and tertiary effects of eco-climatic change: the medical response. *Postgrad Med J* 2010; 86: 230-4.
6. McMichael AJ, Powles JW, Butler CD, Uauy R. Food, livestock production, energy, climate change, and health. *Lancet* 2007; 370: 1253-63.
7. McMichael AJ. Globalization, Climate Change, and Human Health. *N Engl J Med* 2013; 368: 1335-43.
8. McIver L, Hanna L. Fragile paradise - health and climate change in the South Pacific. In: Butler CD, Dixon J, Capon AG (eds). *Health of People, Places and Planet: Reflections based on Tony McMichael's four decades of contribution to epidemiological understanding*. Canberra: ANU Press; 2015.
9. Hanna L, McIver L. Small island states - canaries in the coal mine of climate change and health. In: Butler CD (ed). *Climate Change and Global Health*. Wallingford, UK: CABI; 2014.
10. Haines A, Kovats RS, Campbell-Lendrum D, Corvalan C. Climate change and human health: Impacts, vulnerability and public health. *Lancet* 2006; 367: 2101-9.
11. McMichael AJ, Woodruff RE, Hales S. Climate change and human health: present and future risks. *Lancet* 2006; 367: 859-69.
12. McMichael AJ. Climate change and human health: risks and responses. Geneva: World Health Organization; 2003.

13. Patz J, Campbell-Lendrum D, Holloway T, Foley J. Impact of regional climate change on human health. *Nature* 2005; 438: 310-7.
14. Secretariat of the Pacific Community, 2010. Tuberculosis surveillance in the Pacific Island countries and territories. Noumea, New Caledonia.
15. Donald PR, van Helden PD. The global burden of tuberculosis — combating drug resistance in difficult times. *N Engl J Med* 2009; 360: 2393-5.
16. World Health Organization. Global Tuberculosis Report 2013. Geneva: WHO; 2013. p. 306.
17. Munch Z, Van Lill SWP, Booysen CN, Zietsman HL, Enarson DA, Beyers N. Tuberculosis transmission patterns in a high-incidence area: a spatial analysis. *Int J Tuberc Lung Dis* 2003; 7: 271-7.
18. Lönnroth K, Jaramillo E, Williams BG, Dye C, Ravignone M. Drivers of tuberculosis epidemics: the role of risk factors and social determinants. *Soc Sci Med* 2009; 68: 2240-6.
19. Lawn SD, Zumla AI. Tuberculosis. *Lancet* 2011; 378: 57-72.
20. Jeon CY, Murray MB. Diabetes mellitus increases the risk of active tuberculosis: a systematic review of 13 observational studies. *PLoS Med* 2008; 5: e152.
21. Baker M, Das D, Venugopal K, Howden-Chapman P. Tuberculosis associated with household crowding in a developed country. *J Epidemiol Community Health* 2008; 62: 715-21.
22. Lin H-H, Ezzati M, Murray M. Tobacco smoke, indoor air pollution and tuberculosis: a systematic review and meta-analysis. *PLoS Med* 2007; 4: e20.
23. Marais BJ, Lönnroth K, Lawn SD, *et al.* Tuberculosis comorbidity with communicable and non-communicable diseases: integrating health services and control efforts. *Lancet Infect Dis* 2013; 3099: 1-13.
24. Falagas ME, Bliziotis IA, Kosmidis J, Daikos GK. Unusual climatic conditions and infectious diseases: observations made by Hippocrates. *Enferm Infecc Microbiol Clin* 2010; 28: 716-8.
25. Peers R. The influence of climate upon tuberculosis; with remarks on the climate of Colfax, California. *Cal State J Med* 1908; VII: 106-10.
26. Grant R. Tuberculosis and climate. *J Natl Med Assoc* 1917; 10: 18-21.
27. Trask J. Climate and tuberculosis: the relation of climate to recovery. *Public Health Rep* 1917; 32: 318-24.
28. Douglas AS, Strachan DP, Maxwell JD. Seasonality of tuberculosis: the reverse of other respiratory diseases in the UK. *Thorax* 1996; 51: 944-6.
29. Fares A. Seasonality of tuberculosis. *J Glob Infect Dis* 2011; 3: 46-55.
30. Naranbat N, Nymadawa P, Schopfer K, Rieder HL. Seasonality of tuberculosis in an Eastern-Asian country with an extreme continental climate. *Eur Respir J* 2009; 34: 921-5.
31. Yang X, Duan Q, Wang J, Zhang Z, Jiang G. Seasonal variation of newly notified pulmonary tuberculosis cases from 2004 to 2013 in Wuhan, China. *PLoS One* 2014; 9: e108369.
32. Schipper L, Pelling M. Disaster risk, climate change and international development: scope for, and challenges to, integration. *Disasters* 2006; 30: 19-38.
33. Weiss R, McMichael A. Social and environmental risk factors in the emergence of infectious diseases. *Nat Med* 2004; 10: S70-6.
34. Abayomi A, Cowan MN. The HIV/AIDS epidemic in South Africa: convergence with tuberculosis, socioecological vulnerability, and climate change patterns. *S Afr Med J* 2014; 104: 583.
35. Tuitama LT, Young-soo S, Clark H, Tukuitonga C, Beaglehole R. Acting on the Pacific crisis in non-communicable diseases. *Lancet* 2014; 384: 1823-4.
36. Barrett B, Charles JW, Temte JL. Climate change, human health, and epidemiological transition. *Prev Med (Baltim)* 2014; 70: 69-75.
37. World Health Organization. WHO Multi-Country Cooperation Strategy for the Pacific (2013-2017). Manila: WHO; 2013.
38. Viney K, O'Connor J, Wiegandt A, Lambert M, Cox H, Downing S. Tuberculosis trends in the Pacific: 2000-2006. *Pacific Health Dialog* 2010; 16(1): 157-171.
39. Spence D, Hotchkiss J, Williams C, Davies P. Tuberculosis and poverty. *BMJ* 1993; 307: 759-61.
40. Oxlade O, Murray M. Tuberculosis and poverty: why are the poor at greater risk in india? *PLoS One* 2012; 7: 1-8.
41. Grinafon M, Trébuqç A, Rieder HL. Epidemiology of tuberculosis in Benin. *Int J Tuberc Lung Dis* 2011; 15: 61-6.
42. Baker M, Das D, Venugopal K, Howden-Chapman P. Tuberculosis associated with household crowding in a developed country. *J Epidemiol Community Health* 2008; 62: 715-21.
43. Clark M, Riben P, Nowgesic E. The association of housing density, isolation and tuberculosis in Canadian First Nations communities. *Int J Epidemiol* 2002; 31: 940-5.
44. Ware H. Demography, migration and conflict in the Pacific. *J Peace Res* 2005; 42: 435-54.
45. Taylor R, Rampton D, Lopez AD. Contemporary patterns of Pacific Island mortality. *Int J Epidemiol* 2005; 34: 207-14.
46. Connell J. Environmental change, economic development, and emigration in Tuvalu. 1999; 22: 1-20.
47. Lienhardt C, Fielding K, Sillah JS, *et al.* Investigation of the risk factors for tuberculosis: a case-control study in three countries in West Africa. *Int J Epidemiol* 2005; 34: 914-23.
48. Jha P, Peto R. Global effects of smoking, of quitting, and of taxing tobacco. *N Engl J Med* 2014; 370: 60-8.
49. Danaei G, Finucane MM, Lu Y, *et al.* National, regional, and global trends in fasting plasma glucose and diabetes prevalence since 1980: systematic analysis of health examination surveys and epidemiological studies with 370 country-years and 2.7 million participants. *Lancet* 2011; 378: 31-40.
50. Stevenson CR, Forouhi NG, Roglic G, *et al.* Diabetes and tuberculosis: the impact of the diabetes epidemic on tuberculosis incidence. *BMC Public Health* 2007; 7: 234.
51. Marais BJ, Lönnroth K, Lawn SD, *et al.* Tuberculosis comorbidity with communicable and non-communicable diseases: integrating health services and control efforts. *Lancet Infect Dis* 2013; 13: 436-48.
52. Jeon CY, Murray MB. Diabetes mellitus increases the risk of active tuberculosis: a systematic review of 13 observational studies. *PLoS Med* 2008; 5: e152.
53. Alisjahbana B, Sahiratmadja E, Nelwan EJ, *et al.* The effect of type 2 diabetes mellitus on the presentation and treatment response of pulmonary tuberculosis. *Clin Infect Dis* 2007; 45: 428-35.
54. Asian Development Bank. Food Security and Climate Change in the Pacific - Rethinking the Options. Manila: ADB; 2011.
55. Beaglehole R, Bonita R, Horton R, *et al.* Priority actions for the non-communicable disease crisis. *Lancet* 2011; 377: 1438-47.
56. Food and Agriculture Organization. Climate change and food security in Pacific island countries. Rome: FAO; 2008.
57. McIver L, Woodward A, Davies S, Tibwe T, Iddings S. Assessment of the health impacts of climate change in Kiribati. *Int J Environ Res Public Health* 2014; 11(5): 5224-40.
58. Wu J, Yunus M, Streatfield PK, Emch M. Association of climate variability and childhood diarrhoeal disease in rural Bangladesh, 2000-2006. *Epidemiol Infect* 2014; 142(9): 1859-68.
59. Panic M, Ford JD. A review of national-level adaptation planning with regards to the risks posed by climate change on infectious diseases in 14 OECD nations. *Int J Environ Res Public Health* 2013; 10: 7083-109.

Corresponding Author

Associate Professor Lachlan McIver

College of Public Health, Medical & Veterinary Sciences, James Cook University, Townsville, Queensland, Australia

Email: lachlan.mciver@jcu.edu.au

Chapter Eleven

Paper 8: A “Healthy Islands” framework for climate change in the Pacific

Prelude

This chapter – the last of the publications in the thesis proper – considers the health systems governance factors affecting climate change adaptation to protect health in the Pacific islands.

The paper draws on governance theory, particularly the emerging literature on climate change and health governance, in examining the vulnerability assessment and adaptation planning process as it took place in the three northern Micronesian nations of FSM, Marshall Islands and Palau. The critical issues of agency and authority are explored, and some modest potential advantages of adaptation in the setting of small Pacific island countries are considered.

The discussion is embedded in the “Healthy Islands” vision – the overarching framework for health systems development in the region. In this paper, a Pacific-specific paradigm for health adaptation is presented which builds on the original Healthy Islands framework, some twenty years after its initial formulation.

The candidate’s estimated proportional contributions to this paper were as follows:

Research design:	80%
Analysis and interpretation:	70%
Authorship of paper:	70%

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PERSPECTIVES

A 'Healthy Islands' framework for climate change in the Pacific

Lachlan McIver^{1,†,*}, Kathryn Bowen², Elizabeth Hanna¹, and Steven Iddings^{3,†}

¹National Centre for Epidemiology and Population Health, Australian National University, Canberra, ACT 2601, Australia, ²Melbourne Sustainable Society Institute, University of Melbourne, Melbourne, VIC, Australia, and ³World Health Organization, Cambodia Country Office, Phnom Penh, Cambodia

*Corresponding author. E-mail: lachlan.mciver@gmail.com

†Formerly of World Health Organization Division of Pacific Technical Support, Suva, Fiji.

Summary

Small Pacific Island countries (PICs) are among the most vulnerable countries in the world to the anticipated detrimental health effects of climate change. The assessment of health vulnerabilities and planning adaptation strategies to minimize the impacts of climate change on health tests traditional health governance structures and depends on strong linkages and partnerships between actors involved in these vital processes. This article reviews the actors, processes and contexts of the climate change and health vulnerability assessment and adaptation planning project carried out by the World Health Organization and health sector partners in three island countries in the Micronesian region of the Pacific throughout 2010 and 2011: Federated States of Micronesia, Marshall Islands and Palau. Despite their shared history and cultural characteristics, the findings and implications of this article are considered to have substantial relevance and potential application to other PICs. The modified 'Healthy Islands' framework for climate change and health adaptation presented in this article draws upon real-world experience and governance theory from both the health and climate change literature and, for the first time, places health systems adaptation within the vision for 'Healthy Islands' in the Pacific region.

Key words: climate change, environment and public health, policy and implementation

INTRODUCTION

Anthropogenic climate change is a product of industrialization, economic development, population pressure and globalization that poses myriad risks to society, including detrimental impacts on human health. The health risks

posed by climate change are manifold and occur via complex pathways (McMichael, 2014).

These health effects are measurable, at least in part. The annual global mortality attributable to a small number of specific climate change-related burdens of disease in

the few decades prior to the year 2000 was estimated by the World Health Organization (WHO) to be in the order of 150 000 deaths per year (WHO, 2003). Recent WHO modelling suggests that, by the year 2030, the annual mortality due to climate change impacts on diarrhoeal disease, malaria, malnutrition and heat-related illness will have risen to ~250 000 per year (WHO, 2014a).

The evidence strongly suggests that the burden of disease due to climate change will also be unevenly and inequitably distributed, with a disproportionate burden falling on women and children; people living in poverty; those with pre-existing illnesses and communities in developing countries (WHO, 2003; Patz *et al.*, 2007; Friel *et al.*, 2008). PICs, in particular, may be considered the ‘canaries in the coalmine’ of climate change, due to their heightened vulnerability, which results from a combination of geographic, demographic and socio-economic factors (Hanna and McIver, 2015). Despite their negligible contributions towards global greenhouse gas emissions, PICs suffer the indignity of being among those countries first and hardest hit by the effects, including health impacts, of climate change: ‘. . . the unwanted gift from the developed world’ (Palau Ministry of Health and WHO, 2012).

Responding to the health impacts of climate change tests traditional governance structures, including (but not limited to): the trans-border, cross-cutting nature of the health risks involved; the relative paucity of formal engagement by the health sector in the initial stages of international and national climate change and health vulnerability assessment and adaptation planning work and the requirement to involve multiple sectors in implementing measures to protect health from climate change. Climate change thus resembles other aspects of globalization, such as increased travel and trade, in that it challenges existing health-protective systems and presses the need for a change in the fundamental nature of governance (Dodgson *et al.*, 2002).

This article explores a number of critical issues related to climate change and health governance. Analysed from the perspective of the health vulnerability assessment and adaptation planning project undertaken by WHO and health sector partners, we examine three small island developing states (SIDS) (SIDS were recognized as a distinct group of developing countries facing specific social, economic and environmental vulnerabilities at the United Nations Conference on Environment and Development (otherwise known as the Earth Summit) in Rio de Janeiro, Brazil, in 1992.) in the northern Micronesian region of the Pacific: the Federated States of Micronesia (FSM), Marshall Islands and Palau, as case studies for the wider community of PICs.

In doing so, a context-specific framework for climate change and health governance is posited, which places

climate change within the existing health systems development vision for ‘Healthy Islands’ in the Pacific region, first articulated by the Ministers of Health of the Pacific Islands in their 1995 meeting at Yanuca Island, Fiji, and subsequently hailed in this journal almost two decades ago as a ‘truly ecological model of health promotion’ (Nutbeam, 1996).

BACKGROUND

Marshall Islands, FSM and Palau are neighbouring Pacific SIDS stretching from east to west, just north of the equator. They are small countries in terms of population (2012 World Bank estimates place the population of FSM at 103 395, Marshall Islands at 52 555 and Palau at 20 754.) but, due to their limited land area, have some areas of relatively high population density. Such demographic and geographic factors (including the very low elevation of many of the region’s islands and atolls) contribute to making these among the countries most vulnerable to the physical effects of climate change which, in the Pacific region, are anticipated to include increasing air and sea-surface temperatures; altered rainfall patterns; increasing severity of extreme weather events such as tropical storms; ocean acidification and, of particular concern, rising sea levels (PCCSP, 2011).

In recognition of the health risks posed by climate change, WHO and member states in the Asia-Pacific region compiled a *Regional Framework for Action to Protect Human Health from Effects of Climate Change in the South East Asia and Pacific Region* in 2007 (WHO, 2007).

The health ministers in the Pacific region, at their biennial meeting in Papua New Guinea in 2009, responded with the *Madang Commitment*. This sought to operationalize the previous recommendations by laying out a series of strategies related to planning, coordination, implementation and health systems strengthening in the context of climate change and health adaptation in the Pacific (WHO and Secretariat for the Pacific Community, 2009). These strategies were loosely linked to the ‘Healthy Islands’ framework (Figure 1) (Galea *et al.*, 2000). This model was developed in the mid-late 1990s and encompasses, in the Pacific island context, the actors, context and processes involved in health systems development (Walt and Gilson, 1994).

The aforementioned policies may have been the first by the health sector to specifically address the health impacts of climate change in the region, but it is important to note that these issues had been considered in many PICs as part of their earlier work on climate change vulnerability and adaptation. As part of their initial and subsequent National Communications to the United Nations Framework Convention on Climate Change (UNFCCC) (submitted in the mid- to late-2000s), and via the compilation of

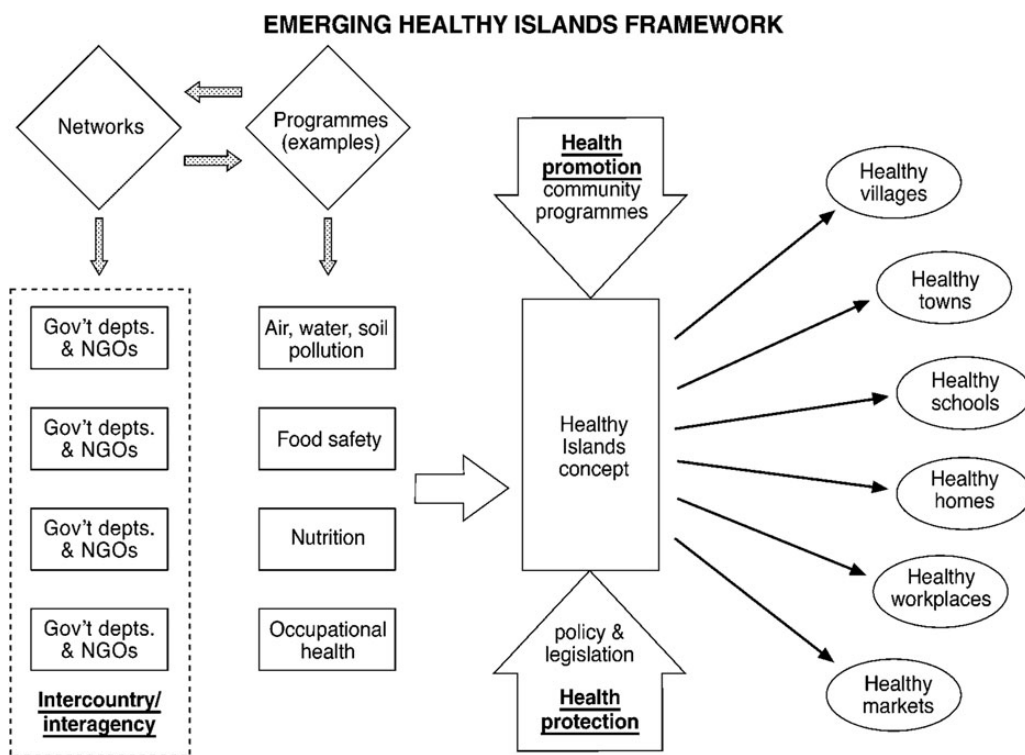


Fig. 1: The original vision for the Healthy Islands framework (reproduced with permission from Galea et al., 2000).

Table 1: Precedents for climate change and health considerations in FSM, Marshall Islands and Palau

FSM	Marshall Islands	Palau
Nationwide Climate Change Policy (2009)	National Climate Change Policy Framework (2011)	Palau Master Plan (draft 2011)
Second National Communication to the UNFCCC (2011 draft)	Joint National Action Plan for Climate Change Adaptation and Disaster Risk Management (draft 2011)	Pacific Adaptation to Climate Change project (2009-current)
National Strategic Development Plan 2003–2023	RMI Strategic Development Plan ('Vision 2018')	National Climate Change Adaptation Plan (draft 2011)

national vulnerability assessments and adaptation plans, several countries in the region noted the potential for climate change to impact on health, even if the general level of understanding of those effects and the substantive contribution of the health sector were limited at that stage (WHO, 2014b).

Part of the explanation for the health sector's apparently slow response to this issue was the assumption that, with respect to mitigation in particular, but also to a lesser extent to adaptation, the actions required would lie largely outside the health domain (Lovell, 2011). As awareness and understanding of the link between climate

change and health increased, however, the fallacy (at least partial) of this assumption was realized.

This realization prompted an urgent review of the health sector's priorities and responsibilities with respect to adaptation in the Pacific. This WHO-supported process, aimed to 'put health at the heart of the climate change agenda' (WHO, 2009) and involved the establishment of some novel linkages between the health and other sectors in these countries.

Table 1 lists some of the key documents and processes that incorporated considerations of the health impacts of climate change in FSM, Marshall Islands and Palau prior

to the WHO and health sector-led vulnerability and adaptation assessment processes of 2010–11.

In the following sections, the actors, processes and contexts of the health vulnerability assessment and adaptation planning work in FSM, Marshall Islands and Palau are described, along with a novel, Pacific-specific climate change and health governance framework, based on the Healthy Islands vision.

PROCESS AND FINDINGS

Throughout 2010 and 2011, the WHO Division of Pacific Technical Support, with support from the WHO Western Pacific Regional Office and funding from the governments of the Republic of Korea and Japan, assisted the FSM Division of Health and Social Affairs (DH&SA), Marshall Islands Ministry of Health (MoH) and Palau MoH in a project that had two aims: assessing each country's vulnerability to the health impacts of climate change and compiling National Climate Change and Health Action Plans (NCCHAPs).

The process of performing each country's vulnerability assessment, and planning adaptation strategies to manage these threats to health, followed WHO guidelines (Kovats *et al.*, 2003) and incorporated both qualitative and quantitative elements. These elements included stakeholder consultations, community surveys, expert consensus and analysis of the available climate and health data.

In-depth discussion of the results of these assessments and plans for adaptation is outside the purview of this article, which focuses on the governance issues related to the vulnerability assessment and adaptation planning process. (Further details regarding the climate change and health vulnerabilities and adaptation plans for these and other countries in the Pacific region may be found in a forthcoming WHO report entitled *Human Health and Climate Change in Pacific Island Countries*, which will link to a supplementary volume containing all

of the respective NCCHAPs.) However, a summary of the highest priority climate-sensitive health risks (as determined by the mixed-methods approach described above) in FSM, Marshall Islands and Palau are presented in Table 2.

The main actors involved in climate change and health adaptation planning as part of the WHO-supported project in each of the three countries are listed in Table 3, with a distinction made between those that coordinated activities and those that were otherwise involved in the process (participants).

There are some important points to note from Table 3. The first is that the table lists only participants in the climate change and health adaptation planning process; many more actors and agencies, particularly community groups, non-government/civil society organizations, educational facilities and others will likely (and necessarily) be involved in implementation of these activities in each country. There was a notable paucity of participation by these latter groups in the planning process; this was inevitably detrimental to the process and was largely due to constraints faced by the coordinating agencies, in particular the short timelines available for consultation.

With respect to geographic representativeness, all four states of FSM were involved in the consultation process, and Palau's highly centralized population was also surveyed as part of the project. In Marshall Islands, however, only representatives of organizations and communities on the capital atoll of Majuro were included, meaning that the outer island perspectives were lacking, as was that of the densely populated atoll of Ebeye.

The second point to note from Table 3 is that, with a few notable exceptions (such as, for example, partnerships between the health sector and other agencies responsible for water safety, supply and sanitation; food safety testing; waste disposal and vector/pest control), prior to this climate change and health work, the health sector had little

Table 2: High priority climate-sensitive health risks in FSM, Marshall Islands and Palau

FSM	Marshall Islands	Palau
Vector-borne diseases (e.g. mosquito-borne viruses such as dengue, Zika)	Vector-borne diseases (dengue)	Vector-borne diseases (dengue)
Water-borne diseases	Water-borne diseases	Water-borne diseases
Food safety, security and malnutrition	Food-borne diseases	Food-borne diseases
Zoonoses (e.g. leptospirosis)	Malnutrition	Zoonoses (leptospirosis)
	Respiratory diseases	Respiratory diseases
		Non-communicable diseases
		Mental health disorders
		Traumatic injuries and deaths (from extreme weather events)

Table 3: Actors involved in climate change and health adaptation planning activities in FSM, Marshall Islands and Palau

Actors	FSM	Marshall Islands	Palau
Coordination	Office for the Environment and Emergency Management	Office of Environmental Planning and Policy Coordination	Pacific Adaptation to Climate Change 'Core Group'
	Department of Health and Social Affairs	Ministry of Health	Ministry of Health
	WHO ^a	WHO ^a	WHO ^a
Participation	Environmental Protection Agency	Environmental Protection Agency	Office for Environmental Response and Coordination
	Weather Service Office	Ministry of Transport and Communication	Bureau of Agriculture
	Department of Resources and Development	Ministry of Resources and Development	Bureau of Marine Resources
	Department of Agriculture	Ministry of Internal Affairs	Environmental Quality Protection Board
	State Health and Environment Services	Weather Service Office	Weather Service Office
	Island Food Community ^b	Chief Secretary's Office	Palau Automated Land and Resources Information System

^aWHO consultants from the University of Nagasaki (Japan), University of Tsukuba (Japan) and Seoul National University (Korea), as well as staff from the Division of Pacific Technical Support participated in the climate change and health vulnerability and adaptation assessments in all three countries.

^bNon-government organization.

reason to work this closely with many of the other actors, despite the earlier mandates from WHO and other UN agencies stretching as far back as the early 1990s (at the time of the abovementioned Earth summit in Rio de Janeiro). This phenomenon will be elaborated below.

DISCUSSION

The unprecedented nature and scale of the health risks posed by climate change has necessitated a relatively radical transformation in the governance processes required to effect the necessary protective measures. This process necessitates embracing interdisciplinary collaborations. The distinctive feature of the new relationships required by climate change lies in the need for health sector actors to reach beyond normal boundaries and engage—simultaneously—with disciplines as diverse as meteorology, agriculture, water, transport and energy.

As argued by Walt and Gilson two decades ago, the actors, process and context of health sector reform—in developing countries such as those under study—are at least as important as the content of the policies themselves (Walt and Gilson, 1994).

The implications for this work on climate change and health in Micronesia and the wider Pacific region are that, while the NCCHAPs contain important and useful information for health adaptation planning, they are only part of a broader process that relies heavily on the engagement

and effective collaboration of appropriate agencies to facilitate adaptation. The NCCHAPs are, in effect, evidence-based policy recommendations; their implementation requires political will, resources and cooperation (McNeill and Ottersen, 2015). In addition, there is the imperative to support mitigation efforts (including within the health sector), enabling of co-benefits (The Intergovernmental Panel on Climate Change (IPCC) defines co-benefits as ‘. . . positive effects on human health that arise from interventions to reduce climate-altering pollutants’. Examples of co-benefits include reducing air pollution and the use of motorized transport.) and the protection of the health of island communities in the face of climate change.

These interlinked concepts are depicted below, in the form of a modified Healthy Islands framework for climate change adaptation (Figure 2).

The framework in Figure 2 makes explicit the original intent of the Pacific health ministers to embed climate change and health adaptation within the Healthy Islands vision (WHO & Secretariat for the Pacific Community, 2009) and builds on the theoretical foundation of earlier work on climate change and health governance (Bowen *et al.*, 2013) in describing a contemporary, real-world example of health systems adaptation to climate change in the Pacific.

In brief, the proposed mechanism for this model of climate change and health policy implementation in the Pacific is as follows: cross-sectoral collaboration from

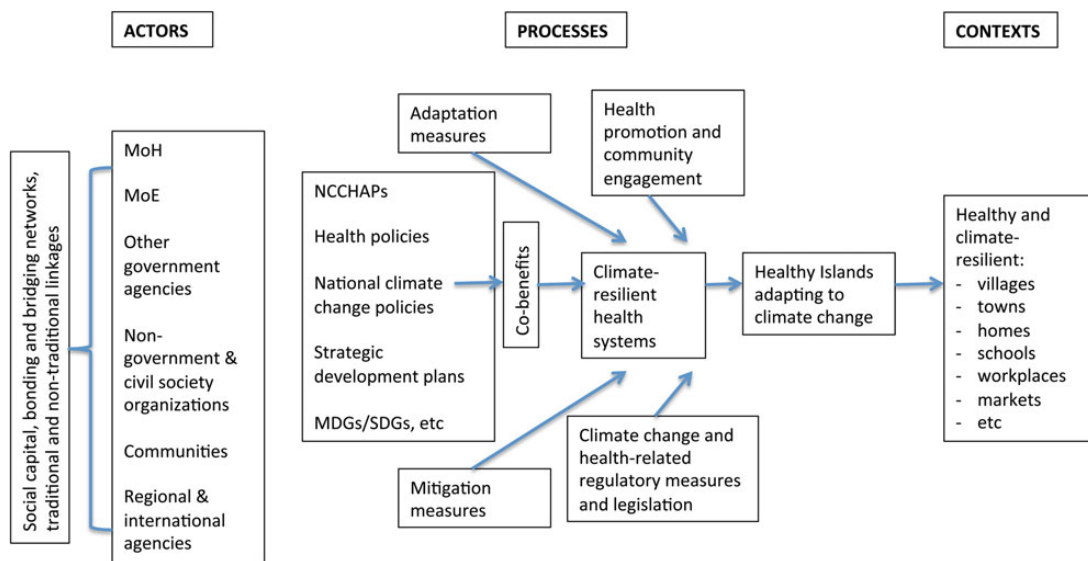


Fig. 2: Healthy Islands framework for climate change adaptation.

multiple actors (across government agencies, non-government and civil society organizations, as well as regional institutions, donors and technical agencies) inform policies and enable appropriate and effective adaptation and mitigation measures to be implemented. These then contribute—in parallel with the processes of engaging the community and regulatory bodies—to the building or strengthening of ‘climate-resilient’ health systems, which protect population health and promote wellness in island communities, in coordination with policies and actions in other areas of society. The model has deliberately been kept close to its initial form, to acknowledge the significance of the original vision, and make clear the opportunity to adapt the model to the climate change context.

It is intended that this model for climate change and health governance and policy development for PICs complement the national vulnerability assessments and adaptation plans completed as part of the WHO regional project. These will be summarized in the aforementioned WHO report entitled ‘Human Health and Climate Change in Pacific Island Countries’, to be published in late 2015.

It has been suggested that an ideal environment for climate change and health governance may include four key elements: social capital, non-state-based actors, informal networks and bridging organizations (Bowen *et al.*, 2013). Each of these elements was represented, to a greater or lesser extent, in the health vulnerability assessment and adaptation planning process in these three study countries.

Of particular interest, with respect to networks and social capital in this context, was the collaboration and level

of cooperation between the health and other sectors on this climate change and health vulnerability and adaptation assessment and planning process, which was reportedly rare and, in some cases—such as the partnership between the government departments of health and meteorology—without precedent.

This is despite earlier regional and global initiatives requiring cross-sectoral-collaboration, such as disaster management, occupational health, tobacco control and the compilation of National Environmental Health Action Plans. While the reasons were not clear, the feedback from these study countries affirmed the novelty of the collaboration across agencies in this context. To quote an official from the Marshall Islands Office of Environmental Planning and Policy Coordination (OEPPC):

... this climate change and health project is the first time we’ve sat and worked together with our colleagues from the Ministry of Health. (Palau Ministry of Health & WHO, 2012)

Within these rarely charted interdisciplinary waters, there also arises the potential for confusion and overlap with respect to authority—here understood to refer to legitimacy or the capacity to exercise power (Biermann *et al.*, 2009; 2010)—when the issue in question can reasonably be seen perceived to fall within the remit of customarily separate or independent actors. Among UN agencies, for example, both WHO and the United Nations Development Programme (UNDP) are highly active in the field of climate change and health adaptation in the Pacific region and

elsewhere. Despite their different mandates—WHO's role is highly technical, while UNDP is an implementing agency—it can be difficult for other organizations, communities and individuals to see and understand the delineation of roles and responsibilities. It is therefore necessary for those involved in health adaptation to be wary of the pitfalls that have been observed to result from proliferation of actors in a relatively small but crowded arena such as health governance. Such unintended negative consequences include lack of accountability, fragmentation of services, duplication of content and competition for resources—financial, human and physical (Gostin and Mok, 2009; Frenk and Moon, 2013).

As described above, health issues had previously been considered in the early stages of adaptation planning by the climate change coordinating agencies in FSM, Marshall Islands and Palau, respectively, the Office of Environment and Emergency Management, OEPPC, and the Pacific Adaptation to Climate Change 'Core Group'. When the health sector in each country subsequently conducted their own climate change and health vulnerability assessments, under the guidance of WHO, this gave rise to the critical question: on whose authority should the resulting adaptation plans be implemented?

In considering this phenomenon of possible confusion and overlap with respect to authority, a distinction has been proposed in the literature between *formal* and *effective* mandates (Lee *et al.*, 1996). (A formal mandate is an agreed statement of an organization's overall purpose or *raison d'être*, usually summarized in a constitution, charter or articles of association/agreement. An effective mandate refers to the actions or exercising of responsibilities of an organization; this may be viewed as how the formal mandates are interpreted and operationalized over time (Lee *et al.*, 1996).) This same distinction may be useful in evaluating the recent history of climate change and health adaptation activities in the three study countries. There, the coordinating agencies were essentially exercising 'effective' authority by taking the initiative to address the problem in the initial stages, while the health sector (including WHO) took longer to respond and exercise its 'formal' authority in conducting health sector-specific vulnerability and adaptation assessments.

The multi-tiered structure of the climate change and health vulnerability and adaptation assessment process, with the division of initiative and responsibility between WHO, the national health agencies and the non-health coordinating agencies, was often opaque in these three study countries, as in other PICs. This raised the prospect of a diminution in the authority of the state actors if, as was entirely possible, it had been perceived that WHO (or other external actors) were setting the agenda.

Despite these issues, a particular feature of governance structures in these three countries enabled a significant degree of representation, participation and transparency when it came to the adaptation planning process. This advantage was largely due to the personal relationships between individuals in positions of influence in these three small countries. Even though the linkages described above between actors and agencies may have been non-traditional, in countries with small populations such as Pacific SIDS, there are often very few 'degrees of separation' between individuals, particularly those who work for government or are prominent in community or other non-government/civil society organizations (Poutiainen *et al.*, 2013). Hence it proved not to be difficult to arrange, for example, high-level meetings between representatives of organizations with scant previous history of collaboration, and there was enthusiasm between some of these new partners (for example, the departments of health and meteorology) to work together on health protection initiatives requiring complementary expertise, such as climate-based early warning systems for communicable disease epidemics.

An additional enabling factor—it could only perversely be considered an advantage—with respect to climate change governance in the study countries is the shared sense of urgency with respect to action on climate change. This common imperative, which extends to health adaptation, is likely to be a significant contributing factor with respect to the willingness of various actors to collaborate.

The combination of high levels of vulnerability, relatively strong policy commitments and some unique governance aspects relating to social capital in these three SIDS have the potential to negate some of their inherent disadvantages, such as small populations and lack of wealth—two factors that have been shown to correlate with weaker adaptation potential and action (Lesnikowski *et al.*, 2013).

Finally, it should be acknowledged again that the contributions of non-government agencies and civil society organizations in both the climate change and health project in the Pacific, and the formulation of the original 'Healthy Islands' vision, was relatively light. Thus, an obvious opportunity to strengthen the model would be to consult more widely with community representativeness and other stakeholders, to ensure the highest levels of relevance and uptake to enable effective policy implementation to protect health.

CONCLUSION

Climate change and health adaptation planning in FSM, Marshall Islands and Palau tested traditional health governance structures. The commencement of health

adaptation planning in the Pacific region two decades prior, without substantial, technically informed health inputs, took the initiative away from the health sector. The WHO-supported vulnerability and adaptation project in PICs formally brought the health sector to the ‘climate change adaptation table’.

As a product of the vulnerability and adaptation assessment process, non-traditional linkages were formed between the health sector and other actors, which enabled more informed and efficient adaptation planning, although it remains to be seen whether this will translate into effective implementation.

The formation of such novel relationships and unprecedented levels of inter-agency collaboration were made possible, in large part, by the strong informal networks and high degree of social capital that exist in such small countries. The strong climate change policy commitments and sense of urgency shared by these and other PICs were found to be important additional catalysts in planning health adaptation strategies.

The process of assessing climate change and health vulnerabilities and planning adaptation strategies in these three countries enabled them to articulate a framework for action on climate change within the Healthy Islands vision for the Pacific. This year, the Pacific health ministers met again in Yanuca and celebrated the twentieth anniversary of the ‘Healthy Islands’ vision. In doing so, they revised the regional health policy approach to that of ‘Islands of Wellness’—a framework well suited to the approach described in this article.

It is intended that this context-specific paradigm for climate change and health governance will facilitate stronger inter-agency coordination and cooperation and clarify important links between relevant policies, processes and people, in an effort to protect the health of these and other Pacific island communities from the health impacts of climate change.

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REFERENCES

- Biermann F., Betsill M., Gupta J., Lebel L., Liverman D., et al. (2009) Earth System Governance: People, Places, and the Planet. Earth System Governance Report 1, IHDP Report 20.
- Biermann F., Betsill M. M., Gupta J., Kanie N., Lebel L., Liverman D., et al. (2010) Earth system governance: a research framework. *International Environmental Agreements: Politics, Law and Economics*, **10**, 277–298.
- Bowen K., Ebi K., Friel S., McMichael A. (2013) A multi-layered governance framework for incorporating social science insights into adapting to the health impacts of climate change. *Global Health Action*, **1**, 1–6. Retrieved from <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3772341/>.
- Dodgson R., Lee K., Drager N. (2002) Global Health Governance: A Conceptual Review. Discussion Paper No. 1. London School of Hygiene and Tropical Medicine and the World Health Organization.
- Frenk J., Moon S. (2013) Governance challenges in global health. *The New England Journal of Medicine*, **368**, 936–942.
- Friel S., Marmot M., McMichael A. J., Kjellstrom T., Vågerö D. (2008) Global health equity and climate stabilisation: a common agenda. *Lancet*, **372**, 1677–1683.
- Galea G., Powis B., Tamplin S. A. (2000) Healthy Islands in the Western Pacific—international settings development. *Health Promotion International*, **15**, 169–178.
- Gostin L. O., Mok E. A. (2009) Grand challenges in global health governance. *British Medical Bulletin*, **90**, 7–18.
- Hanna E., McIver L. (2015) Small Island States—canaries in the coal mine of climate change and health. In Butler C. (ed.), *Climate Change and Global Health*. ANU Press, Canberra, Australia, pp. 181–192.
- Kovats R., Ebi K., Menne B. (2003) Methods of assessing human health vulnerability and public health adaptation to climate change. *Pan American Health*, 4–94. Retrieved from <http://researchonline.lshtm.ac.uk/14942/>.
- Lee K., Collinson S., Walt G., Gilson L. (1996) Who should be doing what in international health: a confusion of mandates in the United Nations? *British Medical Journal*, **312**, 302–307.
- Lesnikowski A. C., Ford J. D., Berrang-Ford L., Berry P., Henderson J., Heymann S. J., et al. (2013) National-level factors affecting planned, public adaptation to health impacts of climate change. *Global Environmental Change*, **23**, 1152–1163.
- Lovell S. A. (2011) Health governance and the impact of climate change on Pacific small island developing states. *IHDP Update*, 50–55.
- McMichael A. (2014) Population health in the Anthropocene: gains, losses and emerging trends. *The Anthropocene Review*, **1**, 44–56.
- McNeill D., Ottersen O. P. (2015) Global governance for health: how to motivate political change? *Public Health*, **129**, 833–837.
- Nutbeam D. (1996) Healthy Islands—a truly ecological model of health promotion. *Health Promotion International*, **11**, 263–264. Retrieved from <http://heapro.oxfordjournals.org/content/11/4/263.short>.
- Pacific Climate Change Science Program. (2011) *Climate Change in the Pacific—Volume 1: Regional Overview*. Australian

- Bureau of Meteorology and the Commonwealth Scientific and Industrial Research Organisation, Canberra.
- Palau Ministry of Health & World Health Organization. (2012) *Palau National Climate Change and Health Action Plan*. Palau Ministry of Health, Koror, Palau.
- Patz J. A., Gibbs H. K., Foley J. A., Rogers J. V., Smith K. R. (2007) climate change and global health: quantifying a growing ethical crisis. *EcoHealth*, 4, 397–405.
- Poutiainen C., Berrang-Ford L., Ford J., Heymann J. (2013) Civil society organizations and adaptation to the health effects of climate change in Canada. *Public Health*, 127, 403–409.
- Walt G., Gilson L. (1994) Reforming the health sector in developing countries: the central role of policy analysis. *Health Policy and Planning*, 9, 353–370. Retrieved from <http://heapol.oxfordjournals.org/content/9/4/353.short>.
- WHO. (2003) Climate Change and Human Health: Risks and Responses. In McMichael A. J., Campbell-Lendrum D. H., Corvalán C. F., Ebi K. L., Githeko A. K., Scherega J. D. and Woodward A. (eds), *Chapters 1–13*. WHO, Geneva.
- Retrieved from http://books.google.com/books?hl=en&lr=&id=tQFYJjDEwhIC&oi=fnd&pg=PP11&dq=Climate+change+and+human+health:+risks+and+responses&ots=PqBvXRXXW_f&sig=jrvKgQTqbUsP-JfDEejVLOHvgVQ.
- WHO and Secretariat for the Pacific Community. (2009) *Madang Commitment*. World Health Organization Western Pacific Regional Office, Manila, Philippines, pp. 13–14.
- World Health Organization. (2007) *Regional Framework for Action to Protect Human Health from Effects of Climate Change in the Asia-Pacific Region*. WHO Western Pacific Regional Office Manila, Philippines, pp. 1–4.
- World Health Organization. (2009) *Protecting Health From Climate Change: Connecting Science, Policy and People*. World Health Organization, Geneva.
- World Health Organization. (2014a) *Quantitative Risk Assessment of the Effects of Climate Change on Selected Causes of Death, 2030s and 2050s*. WHO, Geneva, Switzerland.
- World Health Organization. (2014b) *WHO Guidance to Protect Health From Climate Change Through Health Adaptation Planning*. WHO, Geneva, Switzerland.

Chapter Twelve

Discussion

12.1 Climate change and health vulnerability in the Pacific

The key research questions for this PhD were as follows:

1. What methods may be used to assess climate change and health vulnerabilities in the Pacific, and how do these methods compare in terms of their focus, feasibility, usefulness and relevance to Pacific island countries?
2. What are the most significant risks to health posed by climate change in the Pacific region?
3. What are the main opportunities and challenges in terms of implementing effective climate change and health adaptation strategies in Pacific island countries?

This work described in this thesis attempts to answer these questions and, in doing so, highlights both the extreme susceptibility of Pacific island countries to the health impacts of climate change and the urgent need for effective adaptations to minimise these threats to health. While many of the knowledge gaps, methodological challenges and priorities for further research have been addressed in the preceding chapters, this chapter elaborates on some of the broader issues relevant to the future direction of work on climate change and health in the Pacific region.

Global assessments of climate change and health vulnerability have not been sufficiently fine in spatial scale to consider specifically the unique suite of hazards facing small island states, including those in the Pacific.¹⁻⁴ This is despite the special attention given to such countries by the IPCC,⁵ and even applies to studies of the perceived risk posed by climate change on health in various countries and regions around the world.^{6,7}

While this thesis has addressed the majority of the currently-perceived high-priority risks in Pacific island countries, there remain a number of key issues to be explored in future climate change and health research in the region. These include the psycho-social impacts of climate change (including the consequent prospect of forced relocation) and the ethical and cost-effectiveness dimensions of adaptation.

For many understandable reasons, particularly related to geography and topography, atoll communities feel especially menaced by the seemingly unstoppable forces that threaten

their livelihoods, culture and sovereignty, and which seem to be completely beyond their control. A quote from a community leader in Kiribati recorded as part of the climate change and health vulnerability assessment project there articulates this sense of anxiety and despair:

“To talk about Kiribati is to talk about almost two hundred thousand people whose lives and lands would be wiped out and disappear if climate change and sea-level rise continue. Today, the main issue is not climate change and sea-level rise but survival.

How can the *I-Kiribati* live and preserve their identity and culture if their atoll islands are going to sink? Everything that the people have grown up with will be lost. The sense of belonging, ownership and unity will be replaced by strong heartbreak and lamentation.

This is a global crisis and a serious threat to the livelihood of the Kiribati people. Climate change and sea-level rise are destroying what is most precious to the people of Kiribati¹.”

The quote above highlights at least three issues that are, as yet, inadequately addressed in the climate change and health literature. The first of these is the inequity, unfairness and injustice inherent in the maldistribution of the burden of ill-health due to climate change.

This phenomenon was explored on a global scale in a study that compared the relative contributions of each of the world’s countries to atmospheric greenhouse gas emissions with their respective burdens of projected climate change-related health impacts (using only the four categories of climate-sensitive health risks included in WHO’s previous global risk assessments – diarrhoeal disease, malaria, malnutrition and deaths due to flooding).

The resulting maps, shown in Figure 12.1, demonstrate the dramatic inequalities in contributions versus consequences at the global level.

¹ Reverend Joy Reewi, written submission, South Tarawa, October 2010

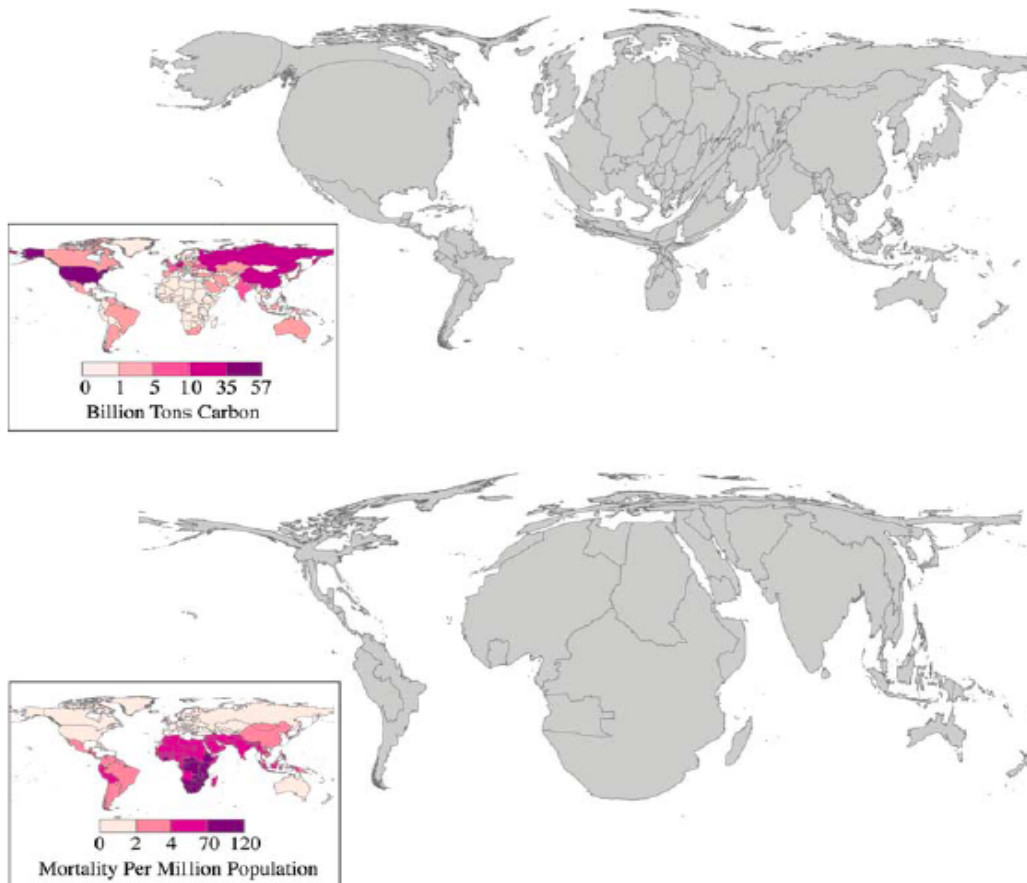


Figure 12.1 Comparison of country-level greenhouse gas emissions (over the period 1950-2000) (top) and burden of climate-sensitive diseases (diarrhoeal disease, malaria, malnutrition and flood-related fatalities).

Source: Patz et al, 2007⁸

While PICs are not clearly shown in Figure 12.1, it can be imagined how small they would appear on the upper map, and how large on the lower. Several papers have discussed the importance of ethical considerations in addressing climate change and health, and the inequities involved.⁹⁻¹¹ These issues are particularly pertinent in PICs, given their extreme vulnerability and severe resource constraints, and must be used to guide current and future adaptation planning in the region.

The second issue raised in the quote from Kiribati is that of the psychological hazard posed by climate change. While the IPCC has included mental health in its most recent risk assessments,¹² there have been surprisingly few studies published on the mental health impacts of climate change. Of the available literature, much attention has been paid to the theory and pathways by which climate change may affect mental health;¹³⁻¹⁷ the psychological consequences of specific climate hazards such as droughts^{18,19} and floods²⁰; and the vulnerabilities of specific groups such as farmers and indigenous peoples.^{21,22}

Significant academic leadership in this area has been shown by social scientists and anthropologists specialising in the Pacific,^{23,24} and a new study is being conducted on climate change and mental health in Tuvalu, but vast amounts remain to be done on this issue in the Pacific region.

A third challenge is the prospect that climate change will lead to forced relocation of individuals, communities and, conceivably, entire countries within the Pacific.^{25,26} The governments of Kiribati and Tuvalu have purchased foreign land specifically for the purpose of enabling emigration. This is clearly no panacea, as migration brings with it its own suite of physical and psycho-social health risks.²⁷ However, some Pacific specialists consider the option of relocation – either internal (within-country) or external (intra-regional or emigration beyond the Pacific) – to be a potential resilience factor for Pacific people, in that it may provide some small protection against the otherwise devastating psychological and emotional consequences of the loss of land and livelihoods.^{28,29}

Despite the relative paucity and inconsistent findings of the literature, it seems very likely that climate change is already having a profound negative effect on the mental health of many Pacific Islanders, in a region where mental health is currently ill-defined, poorly understood and inadequately managed. The identification of mental health as a climate-sensitive health risks in a number of Pacific island countries as part of this project (see Chapter Four) should enable increased resourcing for research and health systems funding for mental health care. Thus robust, well-conducted studies are urgently required to assess the burden of mental health disorders in the Pacific region, and serious efforts made to ascertain the extent to which climate change is affecting mental health at present, and may do so in the future.³⁰ This should lead to the identification of risk factors and at-risk individuals and groups, so that extra support may be provided to minimise long-term psychological distress in this and subsequent generations.

Ranking alongside mental health as a high priority climate change and health vulnerability in the Pacific are non-communicable diseases (NCDs). NCDs have similarly been paid scant attention in the climate change and health literature to date, apart from studies of the direct effects of temperature and air pollution on cardio-respiratory health.³¹⁻³⁵ Chapter Four of this thesis discussed the prominence of NCDs as a category of climate-sensitive health risk in the Pacific, and Chapter Ten considered the specific potential for NCDs such as diabetes to

interact with climate change and communicable diseases as multi-directional mutual risk factors. This “triple burden” of climate change, communicable diseases and NCDs in the Pacific has recently been recognised by WHO,³⁶ and has been addressed in more detail in the aforementioned WHO synthesis report on climate change and health in the Pacific.

12.2 Climate change and health adaptation in the Pacific

The policy response to this complex convergence of challenges will require strong commitment and deft diplomacy, given the overlapping and potentially competing interests of the industry, energy, trade and finance sectors. Thus, a “health in all policies” approach to adaptation has been recommended as a starting point for policy negotiations.³⁷

Adaptation strategies in the region should, of course, be guided by the vulnerability assessments conducted over the last several years and described throughout this thesis. Chapter Four summarised the adaptation strategies common across the Pacific region, and the progress made by some countries, including Fiji, Kiribati and Tonga, in implementing adaptation strategies based on their national climate change and health assessments.

Other PICs have been slower to respond to the recommendations contained with the national action plans for climate change and health. While some of this inertia may be explained by lack of resources or political commitment, it must also be conceded that there is a lack of evidence regarding the effectiveness of adaptation in the available literature, despite the proven efficacy of specific measures such as improving sanitation and increasing “active transport” (i.e. walking or cycling rather than driving).³⁸

The few relevant cost-benefit analyses that do exist suggest that adaptations are rational and effective investments for health systems, particularly for those interventions that have broader health benefits, such as those related to water, sanitation and hygiene (WASH).³⁸⁻⁴¹

Qualitative estimates of the benefits of adaptation have been made based on the major categories of climate change and health vulnerabilities identified at a global level, which are broadly consistent with those in the Pacific, as discussed in Chapter Four.^{42,43}

The IPCC Fifth Assessment Report (2013) depicts the potential reduction in vulnerability via adaptation and mitigation in the diagram below (Figure 12.2), in which the width of the sectors indicates the relative importance of each category of climate-sensitive health risk, and estimated global impact levels are presented for three time periods: the present; the near-term “era of committed climate change” (2030–2040); and for the longer-term “era of climate options” (2080–2100), projected for a global mean temperature increase of 4°C above preindustrial levels. Each of these climate change and health burdens are then shown in terms of the extent to which they may be reduced by effective adaptation and mitigation efforts.¹²

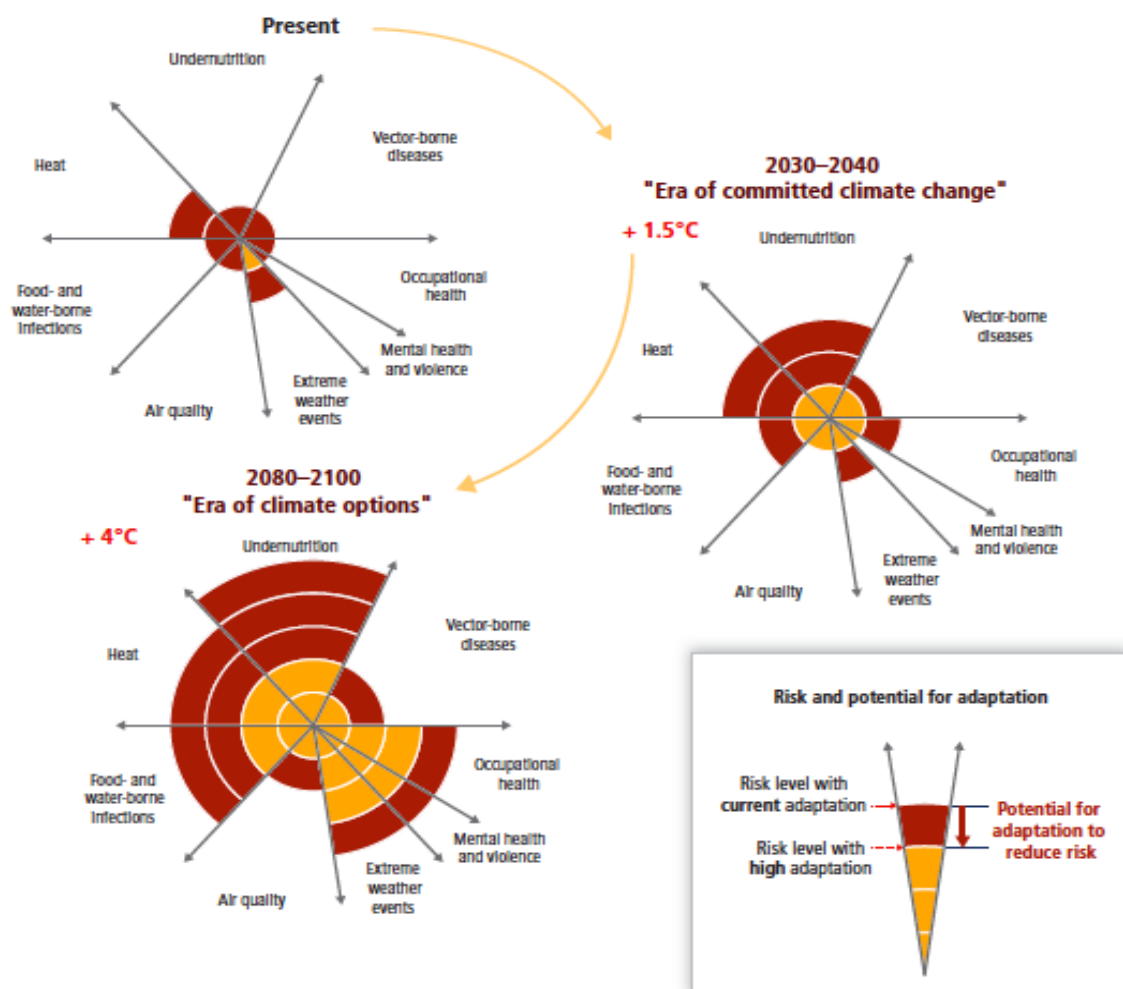


Figure 12.2 Conceptual presentation of the health impacts from climate change and the potential for impact reduction through adaptation

Source: IPCC AR5¹²

Therefore, the recommended approach for policy-makers in the Pacific should be that climate change and health adaptations be considered a cost-effective, low-risk, high-yield investment. While international evaluations of efficacy and cost-benefit are scaled up, the governments of highly vulnerable countries in the Pacific should consider the advice of the authors of one substantial review on the value of climate change and health impacts versus adaptations: “The case for making these expenditures is strong, on economic as well as moral grounds”.³⁹

12.3 Limitations and uncertainties

Of the many areas of uncertainty involved in climate change and health vulnerability assessment and adaptation planning,^{44,45} one of the most substantial is that of estimating future climate change-attributable burdens of ill-health. This challenge, in combining the need for robust climate projection data with the ability to quantify the climate-sensitivity of various diseases, proved impossible for PICs at this point in time, meaning this was an area of general weakness in the region’s climate change and health adaptation plans. Thus, an obvious avenue for future climate and health research in the region will be to obtain and utilise down-scaled projection data for climate over coming decades. This should then be analysed in relation to exposure-response results of historical environmental epidemiological analyses of climate-sensitive diseases, such as those described in this thesis for Fiji and FSM.

Other major limitations of this work were the inconsistencies in the availability and analysis of climate and health data to inform the vulnerability assessments and adaptation plans in PICs. These variations led to methodological differences – for example, the preference for mostly quantitative techniques in some countries and qualitative methods in others. While it has been argued in this thesis that each country’s assessment and plan was appropriate to its needs at the time, at a regional level there are clearly disadvantages in having different methods employed to reach common outcomes that are intended to be comparable.

In compiling the national adaptation plans for climate change and health, it also proved very difficult to estimate the extent to which various strategies may be implemented as a matter of course (i.e. as part of general health systems strengthening measures, as opposed to via

climate change adaptation), and which measures may be redundant over time with socio-economic development. To once again use the WASH example, there is a consensus that improving the safety and security of water, sanitation and hygiene sources and behaviours have far-reaching health benefits,^{46,47} and recognition that these indicators improve with regional and country-level economic development.⁴⁸

So, it could be argued, the emphasis should be on supporting measures to develop economies, raise standards of living and alleviate poverty, rather than strengthening health systems and adapting to climate change. The counter-argument is that these are not mutually exclusive strategies. The small island states in the Pacific clearly require assistance with economic development, but also need urgent support for adaptation to protect community health, as well as their sovereignty, culture and identity. There are strong links between socio-economic development measures and adaptation strategies related to WASH, for example, which both share the ultimate aim of reducing the burden of diarrhoeal diseases.⁴⁹

12.4 Opportunities, research needs and future directions of work

To continue in the theme of mutually beneficial policies, a significant opportunity presents itself in the Pacific in the form of co-benefits – strategies which simultaneously reduce greenhouse gas emissions and improve health outcomes.^{50–53}

In a region burdened by extraordinarily high rates of NCDs,^{54,55} policies aimed at promoting active transport, increasing local agriculture and reducing pollution have the potential to be some of the biggest “win-win” strategies for PICs. The recent Lancet Commission on health and climate change pointed out the wide-ranging benefits to health and society of the major mitigation options, many (but not all) of which apply to the Pacific – see Figure 12.3.

Co-benefits have also been shown to be highly cost-effective results of public health interventions,^{56,57} which should strengthen the argument for these policies to be implemented in the Pacific, despite the negligible contributions of PICs to the problem of excessive global greenhouse gas emissions. The opportunity for PICs to demonstrate moral

and technological leadership in this area is exemplified by the tiny atoll nation of Tokelau recently achieving its goal of sourcing all of its power from renewable energy sources.



Figure 12.3 Co-benefits of major mitigation strategies across aspects of society

(Red arrows: increasing effects; green arrows: reduction in effects)

Source: Watts et al, 2015⁷

Another key opportunity for PICs lies in mainstreaming climate change and health national policies, such as those related to health, environment and economic development; and collaboration across sectors to achieve coherent policy goals. Chapter Eleven described some of the governance challenges encountered in the northern Micronesian countries in this context, but also pointed out the modest comparative advantages that small countries have in enabling cooperation through exercising strong social capital.^{58,59}

The choice of some PICs to combine climate change adaptation plans with disaster risk reduction (e.g. the Joint National Action Plans in Cook Islands, Marshall Islands and Tonga) is one example of such policy mainstreaming.

A further critical area for climate change and health policy relates to research. While the initial national assessment and adaptation planning projects may be officially complete, PICs must now move swiftly to update the information contained with the adaptation plans, implement and evaluate them, all of which should be supported by a strong research framework.

Some of the major areas that are yet to be addressed in climate change and health in the Pacific – and more widely – include:

- Examining the climate-sensitivity of emerging infectious diseases (many of which are zoonoses and/or borne by vectors, making them highly susceptible to environmental variability),⁶⁰⁻⁶² particularly those recently detected or suspected in the Pacific, such as arboviral infections (e.g. Zika and chikungunya) and illnesses caused by soil-transmitted helminths (a cause of significant long-term morbidity, particularly in children) and saprophytes (such as the bacteria causing melioidosis);
- Exploring the utility and feasibility of compiling indices of vulnerability to climate change and health risks, taking into account multiple aspects of vulnerability and resilience, as a means by which to allocate scarce resources to areas and communities most in need;⁶³
- Evaluating national climate change and health adaptation plans in terms of their utility, implementation and effectiveness; and
- Investigating ways to integrate policies and systems to improve the efficiency and efficacy of interventions and adaptation strategies to improve health.^{42,64,65}

A final recommendation arising from the nascent literature on “climate-smart development”, led by the World Bank’s visionary, public health-expert leader, Dr Jim Yong Kim, is to use a framework for development that emphasises the full range of economic benefits and risks, and applies appropriate assessment and financial tools.⁶⁶

This would see bold but evidence-based strategies being implemented that combine a “health in all policies” approach with cost-benefit analyses to achieve climate-resilient health systems⁶⁷ and improved population health.

This should – must – be adopted and supported as the future policy paradigm in the Pacific.

References

- 1 Lopez AD, Mathers CD, Ezzati M, Jamison DT, Murray CJL. Global and regional burden of disease and risk factors, 2001: systematic analysis of population health data. *Lancet* 2006; **367**: 1747–57.
- 2 World Health Organization. Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s. WHO, 2014; Geneva, Switzerland.
- 3 Campbell-Lendrum D, Woodruff R. Comparative Risk Assessment of the Burden of Disease from Climate Change. *Environ Health Perspect* 2006; **114**: 1935–41.
- 4 Patz J, Campbell-Lendrum D, Gibbs H, Woodruff R. Health impact assessment of global climate change: expanding on comparative risk assessment approaches for policy making. *Ann Rev Public Health* 2008; **29**: 27–39.
- 5 Nurse, L.A., R.F. McLean, J. Agard, *et al*, 2014: Small islands. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, VR, *et al*, (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1613-1654.
- 6 Pew Research Global Attitudes Project. Climate Change and Financial Instability Seen as Top Global Threats. Pew Research Center 2013; 1–7.
- 7 Watts N, Adger WN, Agnolucci P, *et al*. Health and climate change: policy responses to protect public health. *Lancet* 2015; **6736**.
- 8 Patz J, Gibbs HK, Foley J a., Rogers J V., Smith KR. Climate Change and Global Health: Quantifying a Growing Ethical Crisis. *Ecohealth* 2007; **4**: 397–405.
- 9 Friel S, Marmot M, McMichael AJ, Kjellstrom T, Vågerö D. Global health equity and climate stabilisation: a common agenda. *Lancet* 2008; **372**: 1677–83.
- 10 Chang AY, Fuller DO, Carrasquillo O, Beier JC. Social Justice, Climate Change, and Dengue. *Health Hum Rights J*; **16**: 93–104.
- 11 Singh JA. Why human health and health ethics must be central to climate change deliberations. *PLoS Med* 2012; **9**: e1001229.
- 12 Smith, K.R., A.Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, and R. Sauerborn, 2014: Human health: impacts, adaptation, and co-benefits. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, CB, *et al* (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 709-754.
- 13 Berry HL, Bowen K, Kjellstrom T. Climate change and mental health: a causal pathways framework. *Int J Public Health* 2010; **55**: 123–32.
- 14 Fritze JG, Blashki G a, Burke S, Wiseman J. Hope, despair and transformation: Climate change and the promotion of mental health and wellbeing. *Int J Ment Health Syst* 2008; **2**: 13.

- 15 Doherty TJ, Clayton S. The psychological impacts of global climate change. *Am Psychol* 2011; **66**: 265–76.
- 16 Albrecht G, Sartore G, Connor L, *et al.* Solastalgia : the distress caused by environmental change. 2007; : 95–8.
- 17 Swim J, Clayton S, Doherty T, Gifford R. Psychology and Global Climate Change: Addressing a Multi-faceted Phenomenon and Set of Challenges. *A Rep by Am Psychol Assoc Task Force Interface Between Psychol Glob Clim Chang* 2009; 1–230.
- 18 Edwards B, Gray M, Hunter B. The Impact of Drought on Mental Health in Rural and Regional Australia. *Soc Indic Res* 2014; published online May 13. DOI:10.1007/s11205-014-0638-2.
- 19 Obrien L V, Berry HL, Coleman C, Hanigan IC. Drought as a mental health exposure. *Environ Res* 2014; **131C**: 181–7.
- 20 Nahar N, Blomstedt Y, Wu B, Kandarina I, Trisnantoro L, Kinsman J. Increasing the provision of mental health care for vulnerable, disaster-affected people in Bangladesh. *BMC Public Health* 2014; **14**: 708.
- 21 Cunsolo Willox A, Harper SL, Ford JD, *et al.* Climate change and mental health: an exploratory case study from Rigolet, Nunatsiavut, Canada. *Clim Change* 2013; published online Sept 8. DOI:10.1007/s10584-013-0875-4.
- 22 McNamara KE, Westoby R. Solastalgia and the gendered nature of climate change: an example from Erub Island, Torres Strait. *Ecohealth* 2011; **8**: 233–6.
- 23 Adger WN, Barnett J, Brown K, Marshall N, O’Brien K. Cultural dimensions of climate change impacts and adaptation. *Nat Clim Chang* 2012; : 1–6.
- 24 Barnett J, Adger WN. Climate Dangers and Atoll Countries. *Clim Change* 2003; **61**: 321–37.
- 25 Locke JT. Climate change-induced migration in the Pacific Region: sudden crisis and long-term developments. *Geogr J* 2009; **175**: 171–80.
- 26 Campbell JR. Climate-Change Migration in the Pacific. *Contemp Pac* 2014; **26**: 1–28.
- 27 Mcmichael C, Barnett J, Mcmichael AJ. An Ill Wind ? Climate Change , Migration , and Health. *Environ Health Perspect* 2012; : 646–54.
- 28 Ware H. Demography, Migration and Conflict in the Pacific. *J Peace Res* 2005; **42**: 435–54.
- 29 Smith R, McNamara KE. Future migrations from Tuvalu and Kiribati: exploring government, civil society and donor perceptions. *Clim Dev* 2014; : 1–13.
- 30 Butler CD, Bowles DC, Mciver L, Page L. Mental Health, Cognition and the Challenge of Climate Change. *Clim Chang Glob Heal* 2014; : 251–9.
- 31 Petkova EP, Morita H, Kinney PL. Health Impacts of Heat in a Changing Climate: How Can Emerging Science Inform Urban Adaptation Planning? *Curr Epidemiol Reports* 2014; published online April 5. DOI:10.1007/s40471-014-0009-1.
- 32 Xu Z, Sheffield PE, Su H, Wang X, Bi Y, Tong S. The impact of heat waves on children’s health: a systematic review. *Int J Biometeorol* 2014; **58**: 239–47.

- 33 Sujaritpong S, Dear K, Cope M, Walsh S, Kjellstrom T. Quantifying the health impacts of air pollution under a changing climate-a review of approaches and methodology. *Int J Biometeorol* 2014; **58**: 149–60.
- 34 Hajat S, Vardoulakis S, Heaviside C, Eggen B. Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. *J Epidemiol Community Heal* 2014; : 1–8.
- 35 Kjellstrom T, Butler AJ, Lucas RM, Bonita R. Public health impact of global heating due to climate change: potential effects on chronic non-communicable diseases. *Int J Public Health* 2010; **55**: 97–103.
- 36 World Health Organization, Western Pacific Regional Office. WHO Multi-Country Cooperation Strategy for the Pacific (2013-2017). 2013; Manila, Philippines.
- 37 World Health Organisation. Health in All Policies - Training Manual. 2015. http://www.euro.who.int/__data/assets/pdf_file/0003/109146/E89260.pdf.
- 38 Hutton G, Menne B. Economic Evidence on the Health Impacts of Climate Change in Europe. *Environ Health Insights* 2014; : 43–52.
- 39 Markandya A, Chiabai A. Valuing climate change impacts on human health: empirical evidence from the literature. *Int J Environ Res Public Health* 2009; **6**: 759–86.
- 40 Haines A, Ebi KL, Smith KR, Woodward A. Health risks of climate change: act now or pay later. *Lancet* 2014; **384**: 1073–5.
- 41 World Health Organization. Climate change and health: a tool to estimate health and adaptation costs. 2013; Geneva, Switzerland.
- 42 Semenza JC. Climate change and human health. *Int J Environ Res Public Health* 2014; **11**: 7347–53.
- 43 Woodward A, Smith K, Campbell-Lendrum D, *et al*. Climate change and health: on the latest IPCC report. *Lancet* 2014; **6736**: 1–5.
- 44 Wardekker JA, de Jong A, van Bree L, Turkenburg WC, van der Sluijs JP. Health risks of climate change: An assessment of uncertainties and its implications for adaptation policies. *Environ Health* 2012; **11**: 67.
- 45 Kolstad EW, Johansson KA. Uncertainties associated with quantifying climate change impacts on human health: a case study for diarrhea. *Environ Health Perspect* 2011; **119**: 299–305.
- 46 Schmidt W-P. The elusive effect of water and sanitation on the global burden of disease. *Trop Med Int Heal* 2014; **19**: 522–7.
- 47 Prüss-Ustün A, Corvalán C. How much disease burden can be prevented by environmental interventions? *Epidemiology* 2007; **18**: 167–78.
- 48 Grasso M, Manera M, Chiabai A, Markandya A. The health effects of climate change: a survey of recent quantitative research. *Int J Environ Res Public Health* 2012; **9**: 1523–47.
- 49 Akanda AS, Jutla AS, Colwell RR. Global diarrhoea action plan needs integrated climate-based surveillance. *Lancet Glob Health* 2014; **2**: e69–70.

- 50 West JJ, Smith SJ, Silva R a., *et al.* Co-benefits of mitigating global greenhouse gas emissions for future air quality and human health. *Nat Clim Change* 2013; **3**: 885–9.
- 51 Ganten D, Haines A, Souhami R. Health co-benefits of policies to tackle climate change. *Lancet* 2010; **376**: 1802–4.
- 52 Wilkinson P, Smith KR, Davies M, *et al.* Public health benefits of strategies to reduce greenhouse-gas emissions: household energy. *Lancet* 2009; **374**: 1917–29.
- 53 McMichael AJ, Lindgren E. Climate change: present and future risks to health, and necessary responses. *J Intern Med* 2011; **270**: 401–13.
- 54 Mannava P, Abdullah A, James C, Dodd R, Annear PL. Health Systems and Noncommunicable Diseases in the Asia-Pacific Region: A Review of the Published Literature. *Asia Pac J Public Health* 2013; published online Oct 4. DOI:10.1177/1010539513500336.
- 55 World Health Organization. Noncommunicable Diseases Country Profiles 2011. WHO, 2011; Geneva, Switzerland.
- 56 Balbus J, Greenblatt J, Chari R, Millstein D, Ebi K. A wedge-based approach to estimating health co-benefits of climate change mitigation activities in the United States. *Clim Change* 2014; 199–210.
- 57 Dora C, Haines A, Balbus J, *et al.* Indicators linking health and sustainability in the post-2015 development agenda. *Lancet* 2014; **385**: 380–91.
- 58 Bowen K, Ebi K, Friel S, McMichael A. A multi-layered governance framework for incorporating social science insights into adapting to the health impacts of climate change. *Glob Health Action* 2013; **1**: 1–6.
- 59 Bowen K, Alexander D, Miller F, Dany V. Using Social Network Analysis to Evaluate Health-Related Adaptation Decision-Making in Cambodia. *Int J Environ Res Public Health* 2014; **11**: 1605–25.
- 60 Weiss R, McMichael A. Social and environmental risk factors in the emergence of infectious diseases. *Nat Med* 2004; **10**: S70–6.
- 61 Lindgren E, Andersson Y, Suk JE, Sudre B, Semenza JC. Monitoring EU emerging infectious disease risk due to climate change. *Science* 2012; **336**: 418–9.
- 62 Thomson MC. Emerging Infectious Diseases, Vector-Borne Diseases, and Climate Change. In: *Global Environmental Change* (Freedman B, ed), 2014; 623–8.
- 63 Hahn MB, Riederer AM, Foster SO. The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. *Glob Environ Chang* 2009; **19**: 74–88.
- 64 Kjellstrom T, McMichael AJ. Climate change threats to population health and well-being: the imperative of protective solutions that will last. *Glob Health Action* 2013; **6**: 1–9.
- 65 Hambling T, Weinstein P, Slaney D. A review of frameworks for developing environmental health indicators for climate change and health. *Int J Environ Res Public Health* 2011; **8**: 1–21.

- 66 The World Bank and ClimateWorks Foundation. Climate-Smart Development: Adding up the benefits of actions that help build prosperity, end poverty and combat climate change. World Bank, 2014; Washington D.C., USA.
- 67 World Health Organization. Essential Public Health Package to Enhance Climate Change Resilience in Developing Countries - Meeting Report. WHO, 2010; 1–27; Geneva, Switzerland.

Chapter Thirteen

Conclusion

13.1 From here to the horizon

This thesis lays an evidence-based foundation for implementing measures to protect population health in Pacific island countries in the face of climate change. It identifies and stratifies risks and prioritises adaptation strategies to a level of scientific rigour and policy-oriented detail unprecedented in the region.

In answering the three key research questions that guided this work – related to optimising the methods of assessing health vulnerability to climate change in the Pacific; identifying the highest-priority climate-sensitive health risks in the region; and planning health systems adaptations to minimise these risks – the research described in this thesis makes clear that Pacific island communities face myriad health hazards attributable to climate change.

These range from communicable to non-communicable diseases; epidemics to natural disasters; acute and clearly apparent illnesses to chronic and cryptic conditions. The methods employed in the vulnerability assessments and adaptation planning processes across the region provide important templates for subsequent iterations and revised assessments and plans. The results of the assessments themselves must be updated regularly as new information, data and modeling techniques become available. These updates must then be incorporated into revised adaptation plans that are aligned and integrated across sectors.

The imperative of addressing climate change in the Pacific has been apparent for some time. In his address to the United Nations Conference of Parties on climate change in Durban, South Africa, in 2011, the *ulu* of the tiny Pacific atoll of Tokelau, Mr Foua Toloa, made plain the plight of Pacific people:

“We stand to lose the most of any country in the world due to climate change and rising sea levels. We will be among the first to go under water. [But] we have a culture, a language, an identity and a heritage. We want to preserve Tokelau for future generations. Climate change does not distinguish between colour or race. It is an everyday reality here. It is our life. If nothing comes [by way of support] from this...then we will continue to suffer¹.”

¹ <http://www.theguardian.com/environment/2011/dec/08/pacific-micro-state-renewable-energy>

It is my hope and intention in conducting this research and writing this thesis that the work described herein may be used as evidence for advocacy and action to protect the health of Pacific people from the damaging effects of climate change.

In doing so, the utmost urgency and pragmatism must be applied, in recognition of the fact that climate change is not just an environmental hazard, or solely a risk to health, but is an overarching, omnipresent obstacle to socio-economic development in the region. The most forceful arguments must be made to use climate change adaptation and mitigation resources to raise the standard of health and well-being in these beautiful but exquisitely susceptible small island states.

Climate change is, as the *ulu* makes clear, a lived experience for Pacific Islanders. This has implications for societies around the globe, as when it comes to the impacts of climate change on human health, the Pacific islands may be considered the canaries in the coalmine.

Annex 1

Fragile Paradise – Health and Climate Change in the South Pacific

*A tribute to Tony McMichael's contribution to
climate change and health*

Prelude

This manuscript was accepted for publication in early 2013, in a profoundly significant textbook entitled “Health of People, Places and Planet - Reflections based on Tony McMichael’s four decades of contribution to epidemiological understanding”.

Published by ANU e-press in the latter half of 2015, the book combines scholarship and advocacy on a broad range of public health issues in which Tony demonstrated far-sightedness, incisiveness and intellectual innovation. Climate change and health was a topic to which Tony dedicated much of the last two decades of his life, and he was – and remains – much respected by his peers as a pioneer and global leader in the field.

This chapter attempts to summarise Tony’s contributions to our collective understanding of the health impacts of climate change, and places his work in the context of the Pacific regional climate change and health project that is the subject of this thesis.

It was with Tony’s encouragement that I embarked upon this doctoral journey, and I hope that my modest contributions may be considered vindication of his support.

Reference: McIver L, Hanna E. Fragile Paradise – Health and Climate Change in the South Pacific. In: *Health of People, Places and Planet – reflections based on Tony McMichael’s four decades of contribution to epidemiological understanding*. Butler C, Dixon J & Capon A (eds). ANU e-press, Canberra, Australia, 2015; Chapter 17, p 337-350.

FRAGILE PARADISE

Health and Climate Change in the South Pacific

LACHLAN MCIVER AND ELIZABETH HANNA

Abstract

Island countries of the South Pacific are among the most vulnerable in the world to the effects of climate change, including the likely detrimental impacts on health. In general, the burden of these impacts falls disproportionately to particular subsectors of the population, such as the socio-economically deprived, certain occupational groups, those with pre-existing illnesses and residents of areas of high exposure to climate-related phenomena such as floods, droughts and sea level rise. Thus, climate change has the potential to exacerbate social and health inequalities further. As part of a suite of adaptations integrated across sectors, protection of Pacific Island communities from climate change-related health threats requires an evidence-based approach that incorporates a context-based assessment of vulnerability.

Pioneering work by McMichael and colleagues in the 1990s and early 2000s provided templates for performing assessments of vulnerability and compiling plans for adaptation to protect human health from the effects of climate change. This chapter reviews the inclusion of the human health dimension in the climate change impact and adaptation research landscape. We summarise the mixed methods approaches employed to assess climate change and health vulnerabilities and adaptation opportunities in the Pacific region. Results of these assessments are provided, key themes are identified and we map the planned direction of health adaptation to climate change in the Pacific.

Background

While it may seem, to some, that the scientific community's interest in and concern about the changing global climate is a relatively recent phenomenon, the reality is radically different. The concurrent rise in post-Industrial Revolution global greenhouse gas emissions and increasing ambient temperatures has been occurring for more than two centuries, and the causal link between the two was first hypothesised in the 19th century, when Arrhenius recognised the relationship between atmospheric carbon dioxide concentrations and the temperature at the Earth's surface (Arrhenius, 1896), building on earlier work that explored the effect of gases and vapour on radiation and heat (Tyndall, 1861).

In the late 1980s, the World Health Organization (WHO) convened a working group to consider the health impacts of the climate change scenarios developed in 1987 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). These scenarios included the possibility of warming air and sea surface temperatures, rising seas and increasing variability and impacts of extreme weather events such as floods, droughts and storms (WMO and UNEP, 1988). The resulting WHO report, entitled 'Potential health effects of climatic change', considered both 'direct' impacts, such as heat-related morbidity and mortality, as well as 'indirect' effects, including the impacts on crops and nutrition, communicable diseases such as those spread by vectors (e.g. malaria, schistosomiasis, lymphatic filariasis) and those related to water quality (e.g. diarrhoeal illness) (WHO, 1990). This early, speculative work has been expanded and refined over recent years, with much of that led by McMichael, who continued to update and improve upon his own conceptual models of the pathways and impacts of climate change on health to incorporate contemporary evidence and reflect the evolution of our understanding of the issues.

The Intergovernmental Panel on Climate Change (IPCC) was convened in 1988, and issued its first report in 1990. Within three years, the WHO was collaborating with the WMO and UNEP in a series of consultations that culminated in the publication of the seminal work, *Climate Change and Human Health*, in 1996. This book laid out the established and potential links between climate variables and the climate-sensitive determinants of health and disease (McMichael et al., 1996). It expanded on the original list of diseases of concern in the context of climate change and laid the epidemiological foundation for investigation of the current and, more importantly, future impacts of climate change on health. In so doing, the authors explained the methodological challenges involved in estimating climate change-attributable impacts and burdens of disease, based on multiple scenarios and layers of uncertainties. It was a pioneering work of

public health research, and its authors were breaking new scientific ground in the exploration of the link between a healthy human population and a healthy planet. The book's first editor was Tony McMichael.

McMichael and a group of close colleagues (including Andy Haines, Jonathan Patz, Diarmid Campbell-Lendrum, Sari Kovats, Carlos Corvalán, Alistair Woodward, Simon Hales, Kris Ebi and Yasushi Honda) published a series of subsequent papers and texts in the late 1990s and early 2000s that undertook the difficult dual tasks of estimating the attribution of climate change causality to the global burden of disease and suggesting strategies to manage these climate change-related threats to health. Assistance with this venture came in the form of the establishment of a small unit within the WHO's Environmental Health team in its Geneva headquarters and research support provided by the London School of Hygiene and Tropical Medicine.

Of the most significant achievements of this group during that period were the compilation of chapters on the potential risks of climate change to human population health for the Second (1996) and Third (2001) Assessment Reports of the IPCC. While the focus was still primarily on the direct health effects of heat and hydrometeorological disasters and the indirect impacts on communicable diseases and malnutrition, by the time of the Third Assessment Report there was growing recognition of the unique vulnerabilities of certain regions (e.g. low-lying island communities) and populations (e.g. developing countries, the socio-economically deprived) (IPCC, 2001). Terms such as 'adaptive capacity' were coined, defined and used to explain both natural and social phenomena in the climate change context.

In 2003, McMichael and colleagues compiled another pivotal work, commissioned by the WHO, WMO and UNEP, entitled *Climate Change and Human Health – Risks and Responses* (McMichael et al., 2003b). One of the most widely referenced texts on the topic ever since, this book built on the growing body of literature describing the pathways by which climate change affected health and, for the first time, quantified the estimated global burden of disease due to climate change (as part of the WHO's 'Comparative Quantification of Health Risks' project in 2000) and reviewed and synthesised the attempts by a number of countries to assess the health impacts of climate change at a national level. The global climate change-attributable burden of disease at that time (using 2000 as a baseline) was estimated at approximately 150,000 deaths per year (McMichael et al., 2004), a figure which included the results of regional assessments, including the Oceania risk assessment, led by McMichael (McMichael et al., 2003b).

This burgeoning regional focus prompted the Western Pacific Regional Office (WPRO) of the WHO to compile a 'Regional Framework for Action to Protect Human Health from the Effects of Climate Change in the Asia Pacific Region'. This important document mandated the WHO to support member countries in the region to assess their vulnerabilities to the health impacts of climate change and develop national strategies and plans to manage those risks (WHO, 2008). The health ministers in the Pacific region responded at their biennial meeting in Madang, Papua New Guinea, in 2009, with the resultant 'Madang Commitment', laying out a series of recommendations related to planning, coordination, implementation and health system strengthening in the context of climate change and health adaptations in the Pacific (WHO, 2009).

It is important to note that, while these may have been the first policy documents from the health sector specifically addressing the health impacts of climate change in the Pacific region, these issues had been considered in many Pacific island countries (PICs) as part of their early work on climate change adaptation. Much of this had been taking place since the early 1990s, often in the absence of significant inputs from the health sector. As part of their Initial National Communications to the United Nations Framework Convention on Climate Change (UNFCCC) (mostly submitted in the mid- to late 2000s), several countries in the region noted the potential for climate change to impact on health, despite the limited level of understanding of those effects at the time.

Also in the late 2000s, the Australian government embarked on an ambitious programme of technical support for PICs in the area of climate science via the Australian Bureau of Meteorology (BOM) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Originally called the Pacific Climate Change Science Program (now the Pacific–Australia Climate Change Science and Adaptation Program), this project included among its key outputs a series of country reports outlining historical climate trends and climate change forecasts for the 21st century in the key areas of temperature, rainfall, sea level rise, ocean acidification and extreme weather events (BOM and CSIRO, 2011).

These regional projects, guidelines and mandates provided the launching pad for another ambitious WHO initiative. Commencing in 2010 and completed in 2012, this project saw the WHO assisting 11 PICs in conducting climate change and health vulnerability assessments and adaptation plans, culminating in National Climate Change and Health Action Plans (or variations thereof) for each of these countries in this most vulnerable of regions.

The following sections summarise the methods employed for – and the results of – these assessments and plans and, in doing so, highlight key knowledge gaps, challenges and opportunities related to the protection of human health from climate change in the South Pacific.

Methods

The 11 PICs involved in the WHO climate change and health project (Federated States of Micronesia, Republic of the Marshall Islands, Palau, Vanuatu, Solomon Islands, Nauru, Kiribati, Tonga, Niue, Cook Islands and Tuvalu) were divided into three groups, based roughly, but not precisely, on geography, along the usual ethnic lines of Polynesia, Melanesia and Micronesia. Each of these three groups was supported by a team of WHO consultants throughout a three-phase project over two years.

The first phase involved inception workshops, which brought together the country representatives and consultants to review the current state of knowledge on climate change and health and discuss vulnerabilities and approaches appropriate to each country. The second phase saw the consultant teams visit each of the countries for further stakeholder consultations – across government and non-government agencies, including community representatives and the private sector – as well as examination of the available local data on climate and climate-sensitive diseases. In the final phase, during return visits to each country, the WHO teams assisted the country teams in drafting National Climate Change and Health Action Plans (NCCHAPs), reflecting each country's key vulnerabilities and adaptation priorities with respect to the country-specific health impacts of climate change.

The process and outcomes described above, while broadly similar across the 11 countries, were nevertheless unique for each country, reflecting the preferred methodological approach and expertise of the consultant groups, the availability of climate and health data (or, more often, the lack thereof) and the particular priorities of the stakeholders and climate change and health teams within each country.

The project in each PIC incorporated, to varying degrees, the separate elements of vulnerability assessments recommended by the WHO (Kovats et al., 2003; Campbell-Lendrum and Woodruff, 2007) and others, including a modified Health Impact Assessment (HIA) approach appropriate to climate change and health (Nelson, 2003; Brown et al., 2011), as well as quantitative estimations of the climate health–disease relationship (Campbell-Lendrum and Woodruff, 2006).

A common and recurring theme throughout this process was the imperative to consider the specific needs of vulnerable groups (such as young children, the elderly, those in poverty, those with pre-existing illnesses and disabilities, those in certain geographic locations – coastal villages, for example – and people engaged in certain occupations, such as fishing, agriculture or construction). Thus, in the context of health systems strengthening related to climate change adaptation, issues of equity and access are cross-cutting, of paramount importance reflecting

yet another area in which McMichael made his mark (Friel et al., 2008; Patz et al., 2008). It is worth highlighting at this point, the irony of inequity in the context of climate change in the Pacific (and other developing countries around the world), vis-à-vis the fact that PICs have contributed the least of almost any country to the problem of greenhouse gas emissions but will be among those countries and communities hit hardest by a changing climate.

A strong feature of carrying out this work in PICs was its qualitative element, achieved by engagement with stakeholders in a series of consultations in each country. This was particularly important, given the very small populations in question (Tuvalu and Nauru vie for the title of the world's smallest independent country, with Tuvalu's population hovering around 10,000; Niue, in free association with New Zealand, has a population of approximately 1,500), under-resourced health systems and health professional capacities stretched to the extreme. While in many cases health data were incomplete, of poor quality, or missing altogether, the relevance and urgency of the challenge is widely acknowledged. Health-sector colleagues and other stakeholders proved willing to engage in the discussions, debates and consensus building that ultimately resulted in assessments and plans that were strong on qualitative inputs, albeit weak quantitatively. This characteristic of the PIC project, where precision was lacking and uncertainty large, meant that the adaptation planning process tended towards a 'no-regrets' approach, consistent with that recommended for smaller and/or developing countries and weaker health systems (Wardekker et al., 2012).

Results

The results of the vulnerability assessments in the 11 above-mentioned countries are summarised in Table 17.1 (McIver, 2012).

Table 17.1 Priority climate-sensitive health risks in Pacific Island countries.

Country	Main climate-sensitive issues
Cook Islands	Dengue fever, diarrhoeal disease
Federated States of Micronesia	Water- and mosquito-borne diseases, malnutrition
Fiji	Dengue fever, typhoid fever, leptospirosis, diarrhoeal disease
Kiribati	Food (safety, security, food-borne diseases), water (safety, security, water-borne diseases) and vector-borne diseases
Nauru	Air quality, food security, non-communicable diseases (NCDs)

Country	Main climate-sensitive issues
Niue	Vector-borne diseases, ciguatera, diarrhoeal disease, respiratory disease, heat-related illness, NCDs, trauma from extreme weather events
Palau	Vector-borne diseases, zoonotic infections, gastroenteritis, respiratory disease, NCDs, trauma from extreme weather events, mental health issues
Republic of the Marshall Islands	Food-, water- and vector-borne (dengue) diseases, respiratory diseases, malnutrition
Solomon Islands	Vector-borne diseases (malaria), respiratory diseases
Tonga	Diarrhoeal diseases, vector-borne diseases (dengue), food security/nutrition, NCDs, injuries and deaths from extreme weather events
Tuvalu	Diarrhoeal disease, respiratory disease, compromised food security and impacts on NCDs
Vanuatu	Food- and water-borne diseases

Source: McIver, 2012.

The priority adaptation strategies for each PIC, outlined in their respective NCCHAPs, relate directly to their key vulnerabilities. Broadly speaking, a holistic but pragmatic approach was taken to the adaptation planning process, with countries strongly favouring adaptation strategies that were feasible – recognising technical capacity limitations and financial constraints – in the context of grossly under-resourced health systems and multiple, often competing, health priorities.

Adaptation strategies were considered under a number of different categories, listed below with examples of specific activities under each category:

- Legislative/Regulatory
 - Reviewing building codes and standards to ensure adequate resilience to hydrometeorological disasters
- Public Education/Communication
 - Developing health promotion materials regarding food safety and protection against water-borne diseases under warmer conditions
- Surveillance/Monitoring
 - Expanding and enhancing ‘syndromic surveillance’ for key climate-sensitive diseases such as diarrhoeal illness and dengue fever
- Ecosystem Intervention
 - Carrying out regular community clean-up activities targeting mosquito breeding sites (e.g. pots, puddles, tins, tyres, coconut shells)

- Infrastructure/Development
 - Retrofitting schools, aged care facilities and public buildings with adequate ventilation and/or air conditioning
- Technological/Engineering
 - Procuring appropriate laboratory equipment for food testing, water monitoring and mosquito identification
- Medical Intervention
 - Refining clinical case definitions for climate-sensitive diseases; stockpiling appropriate medications and supplies for extreme weather events
- Research/Further Information
 - Collecting, collating, synthesising and analysing health data in relation to historical climate variability, with a view to estimating future country-specific, climate change-attributable burdens of disease.

Discussion

As can be seen from Table 17.1, the majority of the climate change and health priorities identified in the PICs largely reflect the long-held concerns of experts in the field: issues such as increasing incidence of food-, water- and vector-borne diseases; the health impacts of heat extremes and natural disasters; and mental health stressors have all been included in earlier conceptual models.

One important area of emerging concern – and a climate change exposure impact pathway largely missing from the conceptual models to date – is the potential for climate change to exacerbate the existing and rapidly increasing burden of non-communicable diseases (NCDs). NCDs were among the top priorities in terms of climate change and health in several PICs, and many participants in the vulnerability assessment and adaptation planning process around the Pacific were firm in their opinion that climate change would lead to a worsening of the NCD ‘crisis’.

The literature on climate change impacts on NCDs is scant; once again, one of the most significant contributions to the topic – a paper that focuses on the pathways between extreme weather events and acute exacerbations of existing disease; adaptation and development opportunities; and the potential for ‘co-benefits’ (see below) – has been made by a group that included the indefatigable Tony McMichael (Friel et al., 2011).

Island countries in the Pacific region have among the highest rates of obesity and NCDs such as hypertension, dyslipidaemia and type 2 diabetes in the world (WHO, 2011a). Concern about this trend has led some countries to take

extraordinary measures, such as the government of Palau declaring a state of emergency in an attempt to access a wider range of resources to tackle the problem. At least some PICs see climate change as a potential additional driver of NCD risk; for example, by further worsening the conditions for domestic agriculture (due to increasing temperatures, variable rainfall, salinisation of soil and other factors) and by decreasing one's willingness or ability to exercise or perform outdoor work in hotter and/or wetter conditions.

An extensive recent online discussion forum on the topic of climate change impacts on NCDs in the Pacific, moderated by the WHO, to which more than 30 prominent stakeholders and community members from a wide range of PICs and backgrounds contributed, found that four key themes emerged in relation to potential solutions to the problem: community education, legislation and government regulation, improved food security (e.g. the propagation of drought- and salt-resistant traditional staples such as taro and cassava) and further research.

Another area in which the Pacific may be unique in terms of the timing and/or nature of climate change impacts on health relates to the combined geographic and demographic vulnerabilities of PICs. In 2000, McMichael and Beaglehole (2000) pointed out the contemporary convergence of globalisation, environmental change and the gradual transition from a world where infectious diseases were the predominant burden of ill health to the new world of NCDs. This transition is taking place, apace, in Pacific atoll nations.

Kiribati and the Marshall Islands provide alarming examples of this confluence of social and environmental determinants of ill health, where NCDs such as diabetes coexist with overcrowding and high rates of smoking – all major risk factors for tuberculosis transmission in these two high-prevalence countries (Clark et al., 2002; Alisjahbana et al., 2007; Lin et al., 2007; Baker et al., 2008; Jeon and Murray, 2008). There is a real and concerning possibility that, in these tiny, very low-lying countries with high population densities, climate change phenomena – in particular, sea level rise – may contribute to the burden of diseases such as tuberculosis by additional forcing of population pressures and NCDs.

Despite these risks, and the challenges of implementing effective adaptations for climate change and health in very small countries with limited capacity in many areas, there are some causes for optimism and examples of innovation and progress in PICs. Some of these examples include:

- **Mainstreaming:** Palau merged its climate change and health team within a larger Pacific Adaptation to Climate Change project, ensuring that health issues were considered in community awareness surveys and adaptation activities such as experimenting with climate-resistant crops and fish and clam aquaculture.

- Infrastructure and health systems development: Kiribati's NCCHAP has been reviewed extensively and implementation of this Plan, which focuses on building environmental health capacity (via direct investment in physical resources as well as training and programme support), is the main objective of a well-funded climate change adaptation project coordinated by the Office of the President, with external donor and technical assistance.
- Research: Fiji is one of seven countries participating in a global climate change and health adaptation pilot project aimed at using climate information for disease early warning systems and improving the abilities of health professionals and communities to manage climate-sensitive health hazards.
- All-hazards planning: Tonga, the Marshall Islands and the Cook Islands have opted to combine plans for climate change adaptation with disaster risk reduction in Joint National Action Plans (JNAPs), thus opening up additional avenues for funding and technical support to manage the threats presented by extreme weather events such as cyclones, floods, droughts and storm surges, which almost certainly will all be affected by climate change.

Finally, and somewhat paradoxically, given the negligible contribution of PICs to the problem of climate change itself, it is clear that these countries have a substantial amount to gain from the potential 'co-benefits' of mitigation strategies, such as increasing the use of active and public transport over motorised vehicles and increasing physical activity in the pursuit of fishing and farming (noting that the loss of the latter skills, particularly in younger generations, is an oft-heard lament in the Pacific) (Ganten et al., 2010).

Conclusion

Most of the scenario-based predictions of climate change impacts pertain to the 21st century; many focus on what our world will look like in the year 2100. Over the past 25 years, Tony McMichael was instrumental in shaping, thinking and guiding research and policy priorities related to the health impacts of climate change. His intellectual footprints can be seen in most, if not all, significant works on the topic; his name dominates reference lists of scholarly publications on climate change and human health. To the end of his long and productive life, he continued to supervise research, analyse data and publish on these issues. Much of his work is of critical significance to climate change and health in the island countries of the South Pacific, including a very recent review of the health aspects of climate change-related migration, co-authored by two generations of McMichaels (McMichael et al., 2012).

Given the vogue for basing future climate scenarios around 2100, it is poignant to note that there are now babies and small children alive today who may still be alive in 2100. What world will they see? By that time, some PICs may be uninhabitable, or at least unrecognisable, from the effects of climate change. What will that mean for the health – physical, emotional, spiritual and mental – as well as the nationhood and identity of the most vulnerable communities in the South Pacific?

While climate change represents one of the most significant challenges to development in small island countries in the 21st century, it also provides a unique opportunity to build resilience in the health sector, address health inequities and pilot new approaches to health protection and improvement, for the betterment of communities in the Pacific and around the world.

References

- Alisjahbana, B., Sahiratmadja, E., Nelwan, E.J., Purwa, A.M., Ahmad, Y., Ottenhoff, T.H.M., et al. 2007. The effect of type 2 diabetes mellitus on the presentation and treatment response of pulmonary tuberculosis. *Clinical Infectious Diseases* 45, 428–35.
- Arrhenius, S. 1896. On the influence of carbonic acid in the air upon the temperature of the ground. *Philosophical Magazine and Journal of Science* 5, 237–76.
- Baker, M., Das, D., Venugopal, K. & Howden-Chapman, P. 2008. Tuberculosis associated with household crowding in a developed country. *Journal of Epidemiology and Community Health* 62, 715–21.
- BOM (Bureau of Meteorology) and CSIRO, 2011. *Climate Change in the Pacific: Scientific Assessment and New Research*. Volume 1: Regional Overview. Volume 2: Country Reports, Melbourne, Australia.
- Brown, H.L., Proust, K., Spickett, J. & Capon, A. 2011. The potential role of health impact assessment in tackling the complexity of climate change adaptation for health. *Health Promotion Journal of Australia* 22, S48–S53.
- Campbell-Lendrum, D. & Woodruff, R. 2006. Comparative risk assessment of the burden of disease from climate change. *Environmental Health Perspectives* 114, 1935–41.

- Campbell-Lendrum D, Woodruff R. 2007. Climate change: quantifying the health impact at national and local levels. Editors, Prüss-Üstün A, Corvalán C. WHO Environmental Burden of Disease Series No. 14. World Health Organization, Geneva, Switzerland, 5-55.
- Clark, M., Riben, P. & Nowgesic, E. 2002. The association of housing density, isolation and tuberculosis in Canadian First Nations communities. *International Journal of Epidemiology* 31, 940–45.
- Friel, S., Marmot, M., McMichael, A.J., Kjellstrom, T. & Vågerö, D. 2008. Global health equity and climate stabilisation: a common agenda. *The Lancet* 372, 1677–83.
- Friel, S., Bowen, K., Campbell-Lendrum, D., Frumkin, H., McMichael, A.J. & Rasanathan, K. 2011. Climate change, noncommunicable diseases, and development: the relationships and common policy opportunities. *Annual Review of Public Health* 32, 133–47.
- Ganten, D., Haines, A. & Souhami, R. 2010. Health co-benefits of policies to tackle climate change. *The Lancet* 376, 1802–04.
- Intergovernmental Panel on Climate Change (IPCC) 2001. *Climate Change 2001: Third Assessment Report, Impacts, Adaptations and Vulnerability of Climate Change* (McCarthy J.J., Canianai O.F., Leary, N.A., Dokken, D.J., White, K.S. (eds)). Cambridge University Press, Cambridge, UK.
- Jeon, C.Y. & Murray, M.B. 2008. Diabetes mellitus increases the risk of active tuberculosis: a systematic review of 13 observational studies. *PLoS Medicine* 5, e152.
- Kovats, R.S., Ebi, K., Menne, B., Campbell-Lendrum, D., Canziani, O.F., Githeko, A., et al. 2003. *Methods of Assessing Human Health Vulnerability and Public Health Adaptation to Climate Change*. WHO, Health Canada, UNEP, WMO, Copenhagen, Denmark. Available at: researchonline.lshtm.ac.uk/14942, accessed 31 December 2013.
- Lin, H.-H., Ezzati, M. & Murray, M. 2007. Tobacco smoke, indoor air pollution and tuberculosis: a systematic review and meta-analysis. *PLoS Medicine* 4, e20.
- McIver, L. 2012. Climate change and health in the Pacific: cause for concern; opportunities for adaptation. *Inform'Action* (the Bulletin of the Secretariat for the Pacific Community), 36, 3–6.
- McMichael, A.J. & Beaglehole, R. 2000. The changing global context of public health. *The Lancet* 356, 495–99.

- McMichael, A.J., Haines, A., Slooff, R. & Kovats, S. (eds) 1996. *Climate Change and Human Health*. World Health Organization, Geneva, Switzerland.
- McMichael, A.J., Campbell-Lendrum, D.H., Corvalán, C.F., Ebi, K.L., Githeko, A., Scheraga, J.D., et al. (eds) 2003. *Climate Change and Human Health – Risks and Responses*. World Health Organization (WHO), World Meteorological Organization (WMO), United Nations Environment Programme (UNEP), Geneva, Switzerland.
- McMichael, A.J., Campbell-Lendrum, D., Kovats, S., Edwards, S., Wilkinson, P., Wilson, T., et al. 2004. Global climate change. In: Ezzati, M., Lopez, A., Rodgers, A. & Mathers, C. (eds) *Comparative Quantification of Health Risks: Global and Regional Burden of Disease due to Selected Major Risk Factors*. World Health Organization, Geneva, Switzerland, pp. 1543–649.
- McMichael A.J., Woodruff R.E., Hales S. 2006. Climate change and human health: present and future risks. *The Lancet*. 367: 859-69
- McMichael, C., Barnett, J. & McMichael, A.J. 2012. An ill wind? Climate change, migration, and health. *Environmental Health Perspectives* 120, 646–54.
- Nelson, D. 2003. Health impact assessment of climate change in Bangladesh. *Environmental Impact Assessment Review* 23, 323–41.
- Patz, J., Cambell-Lendrum, D., Gibbs, H. & Woodruff, R. 2008. Health impact assessment of global climate change: expanding on comparative risk assessment approaches for policy making. *Annual Review of Public Health* 29, 27–39.
- Tyndall, J. 1861. On the absorption and radiation of heat by gases and vapours, and on the physical connection. *Philosophical Magazine* 22, 277–302.
- Wardekker, J.A., de Jong, A., van Bree, L., Turkenburg, W.C. & van der Sluijs, J.P. 2012. Health risks of climate change: an assessment of uncertainties and its implications for adaptation policies. *Environmental Health* 11, 67 10.1186/1476-069X-11-67.
- WHO 1990. Potential Health Effects of Climatic Change – Report of a WHO Task Group. WHO, Geneva, Switzerland.
- WHO 2008. Regional Framework for Action to Protect Human Health from the Effects of Climate Change in the Asia Pacific Region. WHO Western Pacific Regional Office, Manila, The Philippines
- WHO & Secretariat for the Pacific Community 2009. *Madang Commitment*. WHO, Geneva, Switzerland.

WHO 2011. Non-communicable Diseases Country Profiles 2011. WHO, Geneva, Switzerland.

WMO & UNEP 1988. Developing policies for responding to climatic change – a summary of the discussions and recommendations of the workshops held in Villach (28 September–2 October 1987) and Bellagio (9–13 October 1987) under the auspices of the Beijer Institute, Stockholm, Sweden (WMO/TD – 225, April 1988).