Defining Population Health Vulnerability Following an Extreme Weather Event in an Urban Pacific Island Environment: Honiara, Solomon Islands

Eileen S. Natuzzi,^{1,2*} Cynthia Joshua,³ Matthew Shortus,⁴ Reginald Reubin,⁵ Tenneth Dalipanda,³ Karen Ferran,² Audrey Aumua,⁶ and Stephanie Brodine²

¹World Health Organization, Solomon Islands Office, Honiara, Solomon Islands; ²San Diego State University, School of Public Health, San Diego, California; ³Ministry of Health and Medical Services, Honiara, Solomon Islands;

⁴World Health Organization, Vanuatu Office, Port Villa, Vanuatu; ⁵Ministry of Environment, Climate Change, Disaster Management and Meteorology, Honiara, Solomon Islands; ⁶Secretariat of the Pacific Community, Suva, Fiji

Abstract. Extreme weather events are common and increasing in intensity in the southwestern Pacific region. Health impacts from cyclones and tropical storms cause acute injuries and infectious disease outbreaks. Defining population vulnerability to extreme weather events by examining a recent flood in Honiara, Solomon Islands, can help stakeholders and policymakers adapt development to reduce future threats. The acute and subacute health impacts following the April 2014 floods were defined using data obtained from hospitals and clinics, the Ministry of Health and in-country World Health Organization office in Honiara. Geographical information system (GIS) was used to assess morbidity and mortality, and vulnerability of the health system infrastructure and households in Honiara. The April flash floods were responsible for 21 acute deaths, 33 injuries, and a diarrhea outbreak that affected 8,584 people with 10 pediatric deaths. A GIS vulnerability assessment of the location of the health system infrastructure and households relative to rivers and the coastline identified 75% of the health infrastructure and over 29% of Honiara's population as vulnerable to future hydrological events. Honiara, Solomon Islands, is a rapidly growing, highly vulnerable urban Pacific Island environment. Evaluation of the mortality and morbidity from the April 2014 floods as well as the infectious disease outbreaks that followed allows public health specialists and policy makers to understand the health system and populations vulnerability to future shocks. Understanding the negative impacts natural disaster have on people living in urban Pacific environments will help the government as well as development partners in crafting resilient adaptation development.

INTRODUCTION

Pacific Island countries suffer disproportionate negative impacts from climate change despite contributing less than 1% toward the greenhouse gases that cause them. These impacts include sea level rise, changing ocean chemistry, increasing sea and land temperatures, rainfall variability resulting in floods versus droughts, and exposure to more intense storms. Floods are the most common type of disaster worldwide and heavily populated urban Pacific coastal areas are particularly vulnerable to riverine flooding and storm surge that exacerbates land loss and displaces people. The World Risk Report 2014 "The City as a Risk Area" identifies the most at risk countries in the world based on exposure to natural disasters, susceptibility of infrastructure, coping capacities of the government, and adaptive capacities. For the past 5 years four Pacific Island countries, Vanuatu, Tonga, Solomon Islands, and Papua New Guinea, were among the 15 most vulnerable countries.¹ About 69% of all Pacific Island external shocks are due to hydrologic weather events such as cyclones, flooding, storm surge, and landslides.^{2,3} These shocks can adversely affect fragile economies and in some cases erase years of development progress. In the western Pacific tropical cyclones as well as rainfall events are forecasted to increase in intensity under current CO₂ emissions.^{4–7}

Research on the health impacts resulting from climate change is growing. The majority of climate change and public health literature has focused on defining vulnerabilities based on past flood and heat wave events in Europe, Australia,

and the United States.⁸ To date, very little has been reported on the actual health impacts resulting from extreme weather events in the Pacific Islands. Recent reports on the region address the potential health impacts through modeling, but very few studies have looked at the actual human impacts that follow an extreme weather event.^{9–13} This paper describes the direct and indirect health impacts that followed a deadly flash flood event in an urban Pacific Island city, Honiara, Solomon Islands.

The Solomon Islands is an archipelago located 8°S of the equator in the southwestern Pacific Ocean. Just over 600,000 people live on more than 900 islands spread out over 1.3 million km² with a landmass of 28,450 km². The Solomon Islands is the least developed country in the Pacific region with a United Nations Development Program, Human Development Index 2014 ranking of 157 of 187. The country is heavily reliant on outside development aid.¹⁴ Honiara, the capital city, is located on the island of Guadalcanal and is the country's largest urban environment. Honiara is home to nearly 70% of Guadalcanal's population and has a population density of 2,953 people/km². It is the center of commerce, trade, education, health, and governance. Much of Honiara's initial infrastructure was built during World War II with homes and businesses built along low elevation alluvium plains adjacent to Ironbottom Sound and the Mataniko River. Approximately 30% of Honiara's residents live in informal settlements and are underrepresented by census data. Approximately one-third of Honiara's population is less than 15 years of age.^{15,16}

The rainy season in the western Pacific is from November through April averaging 1,365 mm (54 inches) of rainfall. From April 2–4, 2014, Honiara experienced unusually heavy rain that resulted in flash flooding. Intense rainfall began on April 2, 2014 due to a low pressure system stalled 100 km

*Address correspondence to Eileen S. Natuzzi, San Diego State University, School of Public Health, Suite 107A, 320 Santa Fe Drive, Encinitas, CA 92024. E-mail: esnmd@mac.com

south of Guadalcanal. On the first day, 120 mm (5 inches) of rain fell, followed by 163.4 mm (6 inches) of rain the next day. The Mataniko and White Rivers, located within Honiara's boundary began to swell. On April 4, 317.6 mm (13 inches) of rain fell on Honiara and northern Guadalcanal. The Mataniko River burst its banks at approximately 1 PM on April 4 washing away up river villages and severely damaging the main Mataniko River bridge a conduit that connects eastern and western Honiara. Electric, sewage, and water services were disrupted. By April 5, Honiara as well as Guadalcanal Province were declared disaster zones and international aid relief followed despite delays due to flooding of Henderson International Airport and debris damage to the Port of Honiara.

MATERIALS AND METHODS

Health and population data were collected from January 2013 to December 2014. These data included the years prior to and following the flash flood.

Population health impacts. Data on the acute and subacute health impacts that occurred from April 4, 2014 through December 2014 were obtained from a number of sources.

Acute morbidity and mortality. Acute morbidity and mortality data, defined as injury or death occurring within 24 hours of the flood event, were collected from the National Referral Hospital Accident and Emergency records, the clinics in Honiara, and cross referenced with definitive mortality information from the Royal Solomon Island Police Forensic Unit and the National Disaster Management Office. Geographical information system (GIS) mapping was used to define victim location and demographics.

Infectious disease impacts. The Syndromic Surveillance Office of the Ministry of Health and the World Health Organization (WHO) collects case numbers of influenza-like illness (ILI), dengue, malaria, and diarrhea on a weekly basis from the National Referral Hospital and three Honiara City Council health clinics. These data were used to determine post flood outbreaks. Cases before the flood, January 2013 through March of 2014, were contrasted with cases after the flood, April 2014 through December 2014.

Health system and population vulnerability assessment. A vulnerability assessment of the health impacts from the April 2014 floods was used using steps described in the WHO Protecting Health from Climate Change Vulnerability and Adaptation Assessment document and from the Interagency Working Group on Climate Change and Health report.^{17,18} ArcGIS 10.3 was used to create baseline vulnerability maps using Solomon Islands census data from 2009 and the Ministry of Lands and Maps data. Honiara health system infrastructure visits were also performed by one evaluator (EN) during which direct GPS coordinates, evaluation of the size of the population served by the clinic, the condition of the building and its proximity to a river, creek, stream, or coastline were collected. These hand-collected data on vulnerability were compared with GIS-defined vulnerability data as defined by a 500-m buffer created along the Mataniko River and Honiara's coastline. All households as well as health infrastructure falling within the buffer area were counted. Health system infrastructure was ranked as highly vulnerable if two or more hydrologic threats were present, as vulnerable if one hydrologic threat was present, and least vulnerable if

there were no identifiable threats. A paired McNemar test was used to assess comparability of hand-collected site visits versus GIS alone in determining health infrastructure vulnerability. An odds ratio (OR) for injury and death compared risk of living in communities adjacent to the river versus all other Honiara locations was calculated using Honiara's 2009 census data and flood morbidity and mortality data.

Hospital in-patient as well as out-patient bed occupancy rate (BOR) data were obtained from the National Referral Hospital Nursing Bed Control System from April through June 2014. BOR is a measure of hospital utilization and bed occupancy capacity.

All descriptive statistics including Student's *t* test (two sided), McNemars, and OR were performed using STATA v13, StataCorp LP, College Station, Texas. Statistical significance was assessed using an alpha level of 0.05.

RESULTS

Direct impacts on population health. Acute morbidity and mortality. The 33 acute injuries and 21 acute deaths that were accounted for were reviewed for the type of injury, the victim's demographic information, and location where the injury or death occurred. All acute mortality, with the exception of one, occurred in communities located directly adjacent to the Mataniko River. The demographics of the victims killed and injured are summarized in Table 1. Thirteen (62%) of deaths were in victims less than 14 years of age. These deaths accounted for three quarters of the 1,209 years of potential life lost from this event. The most common cause of death was drowning combined with blunt force trauma secondary to being swept away by floodwaters. All fatalities were brought to the Accident and Emergency Department, pronounced dead, and moved to a temporary morgue adjacent to the hospital. One victim, a 4 year old, expired in the National Referral Hospital's Accident and Emergency Department. The remains of an adult female were found submerged but were not recoverable. There were also 10 late deaths and are discussed in the subacute infectious disease impacts section below.

Acute injuries occurred in the same geographic locations as deaths (Figure 1). The 33 acute injury victims tended to be older than mortality victims with an age range of 15–44 accounting for 70% of the injured. The most common injury was near drowning with hypothermia (48%). Additional

TABLE 1
Acute morbidity and mortality

Age (years)	Total deaths by age	Total injuries by age
< 1	1	1
1–14	12	11
15–24	2	7
25–34	3	11
35–44	2	5
45–54	0	1
55–64	0	2
> 65	1	0
Total	21	33

Children less than 14 years of age had the highest mortality (62%) and morbidity (37%) rates. About 29% of deaths were in adult woman between 15 and 44 years of age. These data likely represented mothers at home with their children during the daytime. About 30% of injuries were in men aged 15–44 years old. The total years of potential life lost before age 75/100,000 was 1,209.

FIGURE 1. Geographical information system map showing the location of acute mortality and injury victims on a background of Honiara's population density by census enumeration. About 83% of acute morbidity and mortality from the floods occurred in the informal settlement communities of Vura Creek and Koa Hill located directly adjacent to the Mataniko River. Insert is a map identifying Honiara, Solomon Islands.

injuries included lacerations and soft tissue injuries (43%) and fractures or dislocations (6%). The communities of Vura Creek and Koa Hill, located opposite each other along the Mataniko River, suffered the highest combined injuries and deaths (81%) (25 of 33 injuries, 19 of 21 deaths). The population makeup of these communities was compared with that in the remainder of Honiara. The proportion of children less than 5 years of age, adults over 60 years of age, disabled individuals, and number of women did not differ between the flood-affected and unaffected communities.

Subacute infectious disease impacts. Surveillance for infectious diseases was initiated immediately after the flood through the country's Early Warning and Response Network System (EWARN). There were 8,584 cases of infectious diseases and 10 deaths were recorded.

Influenza-like illness. About 2,134 cases of ILI followed a weak propagating outbreak epidemiology curve with peak cases occurring at 3–4 weeks post flood and continuing to peak, albeit to a lesser extent, at 5-week intervals. Overall, the number of post flood cases of ILI were lower than the corresponding 2013 case rates, but was not significant (-66.3 ;

95% confidence interval [CI]: $-240.7, 108$; $P = 0.4$) (Figure 2). Respiratory infectious disease cultures were not performed due to limited resources.

Vector-borne illnesses. Dengue and malaria cases were graphed from week 1 following the flood and compared with 2013 case rates. About 346 cases of dengue fever and 2,667 cases of malaria were recorded. Both vector-borne diseases were significantly lower following the floods (Figure 3A and B). By 6 months following the floods the number of cases of malaria began to slowly rise. Dengue cases were higher in 2013, when 2,381 cases were diagnosed during an acute outbreak of dengue virus serotype 3 (DENV-3). There were no cases of Zika virus identified.

Diarrhea. Diarrhea cases rose from week 3 and peaked by week 5 following the flood (Figure 4A). The number of cases of diarrhea diagnosed and treated following the floods was 3,876 and was found to be significantly higher than case rates from 2013 (Figure 4B). Stool tests yielded multiple pathogens including *Escherichia coli*, *Shigella*, and rotavirus. Although not endemic to Solomon Islands, cholera testing was included due to the historical high rates of cholera

FIGURE 2. Comparison of influenza-like illnesses from the week of the flood to 20 weeks after with the same period in 2013, the year before the flood. Although initially the cases were higher following the flood when compared with 2013, the difference was not found to be significant (95% CI: -240.7, 108; $P = 0.4$).

infection post floods. There were no cases of cholera diagnosed. Patients less than 5 years of age made up the largest portion of diarrhea cases. When stratified based on type of diarrhea, watery versus bloody, there were more cases of watery diarrhea in children less than 5 years of age than in older patients.¹⁹ About 43% of infants who underwent rota-

FIGURE 3. (A) Comparison of dengue fever cases during the flood with the same period in 2013, the year before the flood. There were significantly lower numbers of cases following the flood than in 2013 (95% CI: -212.6, -41.2; $P = 0.006$). (B) Comparison of malaria cases during the flood with the same period in 2013, the year before the flood. Malaria is endemic in the Solomon Islands. However, there were significantly lower numbers of cases after the flood than in 2013. These results are largely due to aggressive post flood surveillance for reemergence of both dengue and malaria cases. Timely vector control programs are responsible for successful mosquito control (95% CI: -171.9, -7.68; $P = 0.034$).

FIGURE 4. (A) Weekly epidemiology curve for the diarrhea cases following the flood. Arrow marks the week of the flood. Within 10–14 days of the flood, diarrhea cases rose steeply. The diarrhea outbreak was likely due to multiple factors including contamination of city as well as well drinking water, crowding at evacuation centers, and poor hygiene. (B) Comparison of diarrhea cases immediately after the flood with the same period in 2013. Following the floods, there was a significant increase in the diarrhea cases when compared with diarrhea cases seen in 2013 (95% CI: -257.8, -71.9; $P = 0.0014$).

virus testing were positive. Ten deaths occurred in children less than 10 years of age and were attributed to infectious diarrhea. Oral rehydration for infants, children, and adults was the main therapy used for treatment of dehydration.

Health system and population vulnerability assessment. The health impacts following the flood taxed Solomon Islands National Health System due to structural damage as well as increased patient demand. The annual average hospital BOR is normally approximately 200% for the National Referral Hospital. This is not unusual as BOR in developing countries is on average higher than developed countries due to limited health infrastructure. During the week of the flood, the hospital's inpatient BOR dropped to 160–170%, whereas the BOR for the Accident and Emergency Department was over 300%. One month following the flood, the inpatient BOR had risen to 375% due to the diarrhea outbreak. Hospital staff worked extensive hours and medical supplies, in particular intravenous fluids, were exhausted early in the response.

Following the flood 369 (4%) homes and three out of Honiara's nine health clinics were damaged by floodwater inundation. The National Referral Hospital's pediatric, maternal, and neonatal wards were evacuated due to storm surge damage. Based on the vulnerability assessment conducted using site visits and GIS mapping, 75% of Honiara's entire health system was deemed vulnerable to future hydrological events. Four out of nine clinics, serving over 26,000 people, and the National Referral Hospital, which serves the entire country, were ranked highly vulnerable. An additional 33%

of the health system, including the Ministry of Health and the Medical Supply Store, were classified as vulnerable.

The ability to accurately assess vulnerability of Honiara's health system using GIS mapping alone was compared with site visit assessments using McNemar's (exact method) paired test. There was one clinic that GIS failed to include as highly vulnerable due to a creek that was not present on the hydrology shapefiles (visit+, GIS-). The difference between the two methods was not statistically significant ($P = 0.5$, for $N = 10$), suggesting that GIS mapping of health infrastructure vulnerability is a cost-effective initial option. Site visits while arduous and expensive, did, however, allow for assessment of the general condition of clinics.

About 34% of Honiara's households are located within 500 m of a river or the coastline, making them potentially vulnerable to damage or flooding (Figure 5). The vulnerable households correspond to 21,049 people or 29% of Honiara's total population based on a mean household population of seven as reported by the 2009 census and adjusted for a 2.7% annual growth rate.⁵

Individuals living in communities and informal settlement camps adjacent to the river during this flood were 23 times more likely to suffer injury or death (OR: 23.2; 95% CI:

11.97, 44.97). About 80% of homes in Koa Hill and Vura Creek, where the majority of fatalities took place, were built with traditional materials (leaf, cardboard or plastic) as compared with wood, metal, and cement. The number of homes constructed using traditional materials in Koa Hill and Vura Creek communities was higher than the number of homes built with traditional materials in Tavio Ridge, a more affluent community where no significant injuries occurred. The difference, however, was not significant (OR: 13.25; 95% CI: -1.69, -28.19; $P = 0.0741$).

DISCUSSION

Hydrologic disasters accounted for 47% of all natural disasters worldwide in 2014. This single hydrological event occurred on April 4, 2014 in Honiara, Solomon Islands, was responsible for a total of 31 deaths (21 acute deaths, 10 subacute deaths), 33 acute injuries, and a large outbreak of infectious diarrhea. Relative to the total population of the Solomon Islands, the 7.71 person/100,000 mortality rate makes Honiara's flood the most deadly single disaster event of 2014 as reported by the Center for Research on the Epidemiology of Disasters.²⁰ Past publications have described

FIGURE 5. Geographical information system map with a 500 m buffer built around flood and storm surge threats in Honiara, including the coastline and rivers. Health infrastructures including the National Referral Hospital and clinics are marked with red crosses on a background of 2009 population census enumerations. Households are green dots. About 75% of health infrastructure and an estimated 3,007 households in Honiara fall within the 500 m buffer (2,341 households are along the coastline and 666 are along a river floodplain). These data represent a population of at least 21,049 or 29% of Honiara's total population.

property destruction and mortality from floods in Solomon Islands and Fiji but do not detail the health impacts that followed.^{21–25} More recent publications have focused on predicting vulnerability through modeling.^{9,26} Analysis of the health impacts following extreme weather events can reveal valuable information about vulnerability and deficiencies that can assist governments and development partners in building climate change resilient communities. Many epidemiology studies on the health impacts of floods use self-reporting methods to reconstruct flood events.^{27–29} Some combine surveillance data with surveys.³⁰ These types of study designs can introduce recall and reporting bias. To date, our paper is the first comprehensive report documenting the health impacts and vulnerabilities following a specific extreme weather event in the Pacific region based on mortality and morbidity data and on site field assessments of structural damage. More studies like this one are needed to encourage appropriate climate change adaptation by Pacific Island nations and other vulnerable countries worldwide.³¹

Over the past three decades, Pacific urban environments have grown at rates faster than any other urban cities worldwide. This has resulted in haphazard building and outgrowth of sanitation, waste, and water infrastructure. Honiara's population growth rate of 4.3% per year is the highest urban growth rate in the region and is largely due to internal migration and high fertility rates.³² Increasing urbanization has disrupted the social-ecological resilience that in the past has been responsible for protecting rural villages and communities in Solomon Islands from external shocks.³³ Land use attitudes have hindered land reformation as well as the adoption of building regulations and resulted in unmanaged infrastructure in vulnerable locations where the building of unsafe structures occurs. This no doubt contributed to Honiara's flood deaths and acute injuries, the latter of which is likely under reported due to people not seeking help or seeking help at clinics outside of Honiara following their displacement.

The mix of organisms responsible for the diarrhea outbreak and its timing suggests contamination of city drinking water sources by sewage and floodwaters. About 80% of Honiara households obtain their drinking water from the city and the remaining 20% from the rivers as well as rainwater catchment. The peak of the diarrhea cases occurred roughly 5 weeks after the flood and followed the epidemiological pattern of a waterborne outbreak following sewer overflow contaminating surface water.^{34–36} This is consistent with a study of drinking water sampled following monsoonal floods in Pakistan in which 20% of samples were contaminated with a high level of total fecal coliform bacteria (e.g., *E. coli*) *Salmonella*, *Shigella*, and *Staphylococcus aureus*.³⁷ Cann and others found over 60% of waterborne illnesses worldwide were linked to heavy rainfall and flooding. The most common pathogens identified in their paper were viruses (Hepatitis, Norovirus, and rotaviruses), *Vibrio cholerae*, *Leptospira* sp., *Campylobacter jejuni*, and *Cryptosporidium* spp.³⁸ Our study with limited infectious diseases diagnostics could not identify the broader range of pathogens known to be responsible for outbreaks post flooding, such as *Leptospira*, a significant infectious disease pathogen in Pacific Island countries.^{39,40} Development of a robust infectious disease surveillance laboratory nationally or at least sub-regionally is needed to rapidly diagnose a broad portfolio of future infectious outbreaks. This is something the WHO's Asia Pacific Strategy for Emerging

Diseases Program has been working with Pacific Island countries on building.⁴¹

Malaria is endemic to the Solomon Islands and periodic dengue fever outbreaks have occurred throughout the Pacific Islands, including in Honiara in 2013.^{42–44} Flooding, with substantial increases in standing water and vector habitat, commonly results in explosive outbreaks of both, as has been reported in the Dominican Republic and Brazil.⁴⁵ In Honiara, the number of cases of malaria and dengue were lower than the corresponding months during preceding year. This is likely due to early, effective vector control measures. Prompt vector control interventions have been shown to reduce post flood outbreaks and Solomon Islands National Vector-borne Disease Control Program's aggressive and timely vector control measures support these observations.⁴⁶ Limited available historic data on dengue fever cases preceding the floods might have introduced bias into this study as the only data available to contrast with the post flood cases were collected in 2013 during an acute DENV-3 outbreak.

There was no data available on the mental health impacts this natural disaster had on the people of Solomon Islands. Post-traumatic stress disorder, anxiety, and depression have been shown to increase following floods.^{47,48} A review of clinic records, personal stories, and news reports did reveal there was much anxiety about the injuries, illnesses, and deaths as well as distress over property loss. This was manifested by expressions of fear, irritability, and violence. Two months following the floods, one-third of people who were still displaced and living in evacuation centers at schools and churches exhibited their frustration through civil unrest and the burning of public buildings. Indirectly, the flood made the government as well as the people of the Solomon Islands more acutely aware of the impact climate change is having on their lives.

Floods can adversely impact the health system infrastructure, the medical supply chain, and the well-being and availability of health-care providers working at hospitals and clinics.^{49,50} The floods in Honiara made it abundantly clear how vulnerable the health system infrastructure is to riverine and coastal flooding. During this natural disaster, the National Referral Hospital, the center of the country's health delivery system, along with three busy clinics serving over 26,000 people were damaged by floodwaters and storm surge necessitating closure and evacuation of patients. The National Referral Hospital, while the tertiary care center for the country, serves a second role as the local provincial hospital for the people of Honiara and Guadalcanal. This dual importance makes assuring its function and safety during times of natural disasters a priority so the health system can maintain vital services despite significant external threats.

SUMMARY

There will be more natural disasters due to a changing climate, which will have impact on the people of the Pacific Islands. The probability of more intense future storms, floods, and droughts is predicted with high likelihood as is evidenced by Honiara's flood, Cyclone Pam in Vanuatu, and Cyclone Winston in Fiji.⁵¹ Geographic isolation, small populations, and a paucity of resources limit the ability to have an economy of scale and severely impedes the delivery of services as well as emergency aid making regional resilience a critical component

of adaptation development. New vector-borne threats, like Zika virus, along with endemic threats can be effectively reduced with early initiation of aggressive mosquito control post disaster. Hospitals and health clinics built away from flood plains and constructed with materials that can withstand external shocks will allow uninterrupted delivery of health care. The regulation of land use adjacent to rivers and the coastline and establishment of safe building codes will minimize future morbidity and mortality. Extreme weather events, like this flood and subsequent cyclones, can erase years of development and undermine a country's fragile economy. Policies and programs that combine climate change adaptation with baseline development can help vulnerable Pacific Island urban environments achieve growth in the face of risk.^{52,53}

Received March 6, 2016. Accepted for publication March 31, 2016.

Published online April 18, 2016.

Acknowledgments: The authors wish to thank Dr Zohir Chowdhury: San Diego State University School of Public Health, Dr Alan Sweedler: San Diego State University Assistant Vice President of International Programs, Christie Lee: Accident and Emergency triage charge nurse, Rhianny Hatamane: NRH Bed occupancy data nurse, Lloyd Tahani: SI Meteorological Service, Michael Kikiolo and Elizabeth Ragimana: Central Bank of Solomon Islands, Maude Ruest: World Bank SI, Walford Devi: Royal Solomon Islands Police Forensics Director, Rita Fahy and Jennifer Anga: Honiara City Council, Dr Joel Denty: Guadalcanal Province Medical Director, Phil Bright: Secretariat of the Pacific Community Pacific Census Data and GIS data, Ministry of Lands: Solomon Islands, Ministry of Education: Solomon Islands, the entire staff at WHO Solomon Islands office, To the Honiara health clinic nurses for sharing their data and for sharing their stories and especially to the communities in Honiara affected by the floods for sharing their stories.

Authors' addresses: Eileen S. Natuzzi, World Health Organization, Solomon Islands Office, Honiara, Solomon Islands, and San Diego State University, School of Public Health, San Diego, CA, E-mail: esnmd@mac.com. Cynthia Joshua, World Health Organization, Solomon Islands Office, Honiara, Solomon Islands, E-mail: joshuac@wpro.who.int. Matthew Shortus, World Health Organization, Solomon Islands Office, Port Villa, Vanuatu, E-mail: shortusm@wpro.who.int. Reginald Reubin, Ministry of Environment, Climate Change, Disaster Management and Meteorology, Honiara, Solomon Islands, E-mail: grkiuts@gmail.com. Tenneth Dalipanda, Ministry of Health and Medical Services, Solomon Islands, Honiara, Solomon Islands, E-mail: dalipandateneth@gmail.com. Karen Ferran and Stephanie Brodine, San Diego State University, School of Public Health, San Diego, CA, E-mails: kferran@mail.sdsu.edu and sbrodine@mail.sdsu.edu. Audrey Aumua, Deputy Director-General of the Pacific Community (SPC), Suva, Fiji, E-mail: aureya@spc.int.

REFERENCES

1. Alliance Development Works and United Nations University, Institute for Environment and Human Security, 2014. *World Risk Report 2014*. Available at: <http://worldriskreport.entwicklung-hilft.de/WorldRiskReport.435.0.html>. Accessed January 2015.
2. Keener V, Marra J, Finucane M, Spooner D, Smith M, eds., 2012. *Climate Change and Pacific Islands: Indicators and Impacts*. Report for the 2012 Pacific Islands. Regional climate assessment. Washington, DC: Island Press.
3. World Bank, 2013. *Acting on Climate Change and Disaster Risk for the Pacific*. Available at: http://www-wds.worldbank.org/external/default/WDSPContentServer/WDSP/IB/2013/11/20/000442464_20131120105129/Rendered/PDF/808690Revised000Box379874B00PUBLIC0.pdf. Accessed July 2015.
4. IPCC SR, 2012. *Managing risk of extreme events and disasters to advance climate change adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM, eds. Cambridge, UK, and New York, NY: Cambridge University Press, 582.
5. IPCC AR5, 2013. *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, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM, eds. Cambridge, United Kingdom and New York, NY: Cambridge University Press, 1535.
6. Knudson T, McBride J, Chan J, Emanuel K, Holland G, Landsea C, Held I, Kossin J, Srivastava A, Sugi M, 2010. Tropical cyclones and climate change. *Nat Geosci* 3: 157–163.
7. Australian Bureau of Meteorology (BOM) and Commonwealth Scientific and Industrial Research Organization, 2014. *Climate Variability, Extremes and Change in the Western Tropical Pacific: New Science and Updated Country Reports*. Available at: <http://www.pacificclimatechangescience.org/publications/reports/climate-variability-extremes-and-change-in-the-western-tropical-pacific-2014/>. Accessed May 2015.
8. World Health Organization. European Union, 2010. *Extreme Weather Events and Public Health Responses*. Springer-Verlag.
9. Spickett JT, Katscherian D, 2014. Health impacts of climate change in the Solomon Islands: an assessment and adaptation action plan. *Glob J Health Sci* 261–273.
10. 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.
11. Bannister-Tyrrell M, Williams C, Ritchie SA, Rau G, Lindesay J, Mercer G, Harley D, 2013. Weather-driven variation in dengue activity in Australia examined using a process-based modeling approach. *Am J Trop Med Hyg* 88: 65–72.
12. 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.
13. Morrow G, Bowen K, 2014. Accounting for health in climate change policies: a case study of Fiji. *Glob Health Action* 7: 23550.
14. Program United Nations Development, 2014. *Human Development Report 2014*. Available at: <http://hdr.undp.org/en/content/human-development-report-2014>. Accessed January 2015.
15. Solomon Islands National Statistical Office, 2009. *Solomon Islands Census Data 2009 National Report*. Available at: <http://www.spc.int/prism/solomons/>. Accessed January 2015.
16. United Nations Country Data, 2015. *Solomon Islands*. Available at: <http://data.un.org/CountryProfile.aspx?crName=solomon%20islands>. Accessed October 2015.
17. Ebi Kristie, 2013. *WHO Protecting Health from Climate Change Vulnerability and Adaptation Assessment*. Geneva, Switzerland: WHO Press.
18. The Interagency Working Group on Climate Change and Health, 2014. *A Human Health Perspective on Climate Change: A report Outlining the Research Needs on the Human Health effects of Climate Change*. San Bernadino, CA: Environmental Health Perspectives and the National Institute of Environmental Health Sciences.
19. WHO Western Pacific Region Solomon Islands Office, 2014. Data from: Forrest Jones, Solomon Islands Diarrhea Outbreak Health Situation Report One, June 5, 2014. Available at: http://www.wpro.who.int/southpacific/programmes/communicable_diseases/disease_surveillance_response/Sitrep-No1SolomonIslands.pdf. Accessed April 2015.
20. Guha-Sapir D, Hoyois P, Below R, 2015. *Annual Disaster Statistical Review 2014*. Brussels, Belgium: Center for Research on the Epidemiology of Disasters, Universite. Catholique de Louvain.
21. Britton N, 1987. Disaster in the south Pacific: impact of tropical cyclone "Namu" on the Solomon Islands, May 1986. *Disasters* 11: 120–133.
22. Blong R, Radford D, 1993. Deaths in natural hazards in the Solomon Islands. *Disasters* 17: 1–11.
23. Radford D, Blong R, 1991. Assessment of natural hazards in the Solomon Islands and implications for other Pacific Island countries. *ADRO* 4: 3–9.
24. D'Aubert A, Nunn P, 2012. *Furious Winds and Parched Islands: Tropical Cyclones (1558–1970) and Droughts (1722–1987) in the Pacific*. New South Wales, Australia: Xlibris Corporation.

25. Yeo S, Blong R, 2010. Fiji's worst natural disaster: the 1931 hurricane and flood. *Disasters* 34: 657–683.
26. Australian Bureau of Meteorology, Commonwealth Scientific and Industrial Research Organisation, 2012. Climate change in the Pacific: scientific assessment and new research. Vol. 2: Country Reports. Chapter 13: *Solomon Islands*. Available at: <http://www.pacificclimatechangescience.org/wp-content/uploads/2013/09/Volume-2-country-reports.pdf>.
27. Bich T, Quang L, Ha L, Hanh T, Guha-Sapir D, 2011. Impacts of flood on health: epidemiologic evidence from Hanoi, Vietnam. *Glob Health Action* 4: 6356.
28. Kunii O, Nakamura S, Abdur R, Wakai S, 2002. The impact on health and risk factors of the diarrhoea epidemics in the 1998 Bangladesh floods. *Public Health* 116: 68–74.
29. Alderman K, Turner L, Tong S, 2013. Assessment of the health impacts of the 2011 summer floods in Brisbane. *Disaster Med Public Health Prep* 7: 380–386.
30. Milojevic A, Armstrong B, Hashizume M, McAllister K, Faruque A, Yunus M, Kim Streatfield P, Moji K, Wilkinson P, 2012. Health effects of flooding in rural Bangladesh. *Epidemiology* 23: 107–115.
31. Barnett John, John C, 2010. *Climate Change and Small Island States: Power, Knowledge and the South Pacific*. New York, NY: Taylor and Francis.
32. Story D, Connell J, 2013. *The Pacific Islands: Environment and Society. Chapter 26: Urban Challenges*. Honolulu, HI: University of Hawaii Press.
33. Lauer M, Albert S, Aswain S, Halpern B, Campanella L, LaRose D, 2013. Globalization, Pacific Islands, and the paradox of resilience. *Glob Environ Change* 23: 40–50.
34. Rose J, Wu F, 2015. Waterborne and foodborne diseases. Levy B, Patz J, eds. *Climate Change and Public Health*. New York, NY: Oxford University Press, 157–172.
35. Levy B, Patz J, eds., 2015. *Climate Change and Public Health*. New York, NY: Oxford University Press.
36. McLellan S, Hollis E, Depas M, Van Dyke M, Harris J, Scopel C, 2007. Distribution and fate of *Escherichia coli* in lake Michigan following contamination with urban storm water and combined sewer overflows. *J Great Lakes Res* 33: 566–580.
37. Ali Khan F, Ali J, Ullah R, Ayaz S, 2014. Bacteriological quality assessment of drinking water available at the flood affected areas of Peshawar. *Toxicol Environ Chem* 95: 1448–1454.
38. Cann K, Thomas D, Salmon R, Wyn-Jones A, Kay D, 2013. Systematic review: extreme water-related weather events and waterborne disease. *Epidemiol Infect* 141: 671–686.
39. Weinberger D, Baroux N, Grangeon J, Ko A, Goarant C, 2014. El Nino southern oscillation and leptospirosis outbreaks in New Caledonia. *PLoS Negl Trop Dis* 8: e2798.
40. Reperan L, Osterhaus A, 2014. The human-animal interface. Atlas R, Maloy S, eds. *One Health: People, Animals and the Environment*. Washington, DC: ASM Press.
41. WHO Asia Pacific Strategy for Emerging Diseases, Progress Report 2013. *Securing Regional Health*. Available at: http://www.wpro.who.int/publications/PUB_ISBN/en/. Accessed December 2013.
42. Cao-Lormeau V, Roche C, Musso D, Mallet H, Dalipanda T, Dofai A, Nogareda F, Nilles EJ, Aaskov J, 2014. Dengue virus type 3, south Pacific Islands, 2013. *Emerg Infect Dis* 20: 1034–1036.
43. Nogareda F, Joshua C, Sio A, Shortus M, Dalipanda T, Durski K, Musto J, Puiahi E, Dofai A, Aaskov J, Cao-Lormeau VM, Musso D, Dutta N, Fleisch J, Nilles E, 2013. Ongoing outbreak of dengue serotype-3 in Solomon Islands, January to May 2013. *Western Pac Surveill Response J* 4: 1–5.
44. Arima Y, Chiew M, Matsui T, 2015. Epidemiological update on the dengue situation in the western Pacific region 2012. *Western Pac Surveill Response J* 6: 82–89.
45. Kouadio I, Ajunid S, Kamigaki T, Hammad K, Oshitani H, 2012. Infectious diseases following natural disasters: prevention and control measures. *Expert Rev Anti Infect Ther* 10: 95–104.
46. Maes P, Harries AD, Van den Bergh R, Noor A, Snow RW, Tayler-Smith K, Hinderaker SG, Zachariah R, Allan R, 2014. Can timely vector control interventions triggered by atypical environmental conditions prevent malaria epidemics? A case-study from Wajir County, Kenya. *PLoS One* 9: e92386.
47. Fernandez A, Black J, Jones M, Wilson L, Salvador-Carulla L, Astell-Burt T, Black D, 2015. Flooding and mental health: a systematic mapping review. *PLoS One* 10: e0119929.
48. Telles S, Singh N, Joshi M, 2009. Risk of posttraumatic stress disorder and depression in survivors of the floods in Bihar, India. *Indian J Med Sci* 63: 330–334.
49. Burki T, 2015. Floods in Myanmar damage hundreds of health facilities. *Lancet* 386: 843.
50. Minh H, Anh T, Rocklov J, Bao Giang K, Trang le Q, Sahlen KG, Nilsson M, Weinehall L, 2014. Primary healthcare system capacities for responding to storm and flood-related health problems: a case study from a rural district in central Vietnam. *Glob Health Action* 7: 23007.
51. IPCC AR5, 2014. *Climate Change 2043: Impacts, Adaptation and Vulnerability Part B: Regional Aspects. Contribution of Working Group IIB to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL, eds. Cambridge, United Kingdom and New York, NY: Cambridge University Press, 688.
52. ADB, 2015. *Asian Development Bank and Solomon Islands: Factsheet*. Available at: <http://www.adb.org/publications/solomon-islands-fact-sheet>. Accessed September 2015.
53. ADB, 2015. *Corporate Evaluation Study. ADB Support to Small Pacific Island Countries*. Available at: <http://www.adb.org/documents/adb-support-pacific-small-island-countries>. Accessed September 2015.