WATER, SANITATION AND DISASTER MANAGEMENT IN ISOLATED SETTLEMENTS IN THE PACIFIC ISLANDS

Eunice P. Vhiriri, Yoland Irwin, Roman Tandlich
Faculty of Pharmacy, Rhodes University [1]
paidamoyovee@gmail.com, y.irwin@ru.ac.za, roman.tandlich@gmail.com
Richard K. Laubscher
Institute for Environmental Biotechnology, Rhodes University [2]
r.laubscher@ru.ac.za

Abstract

Inadequate sanitation and drinking water facilities play a role in transmission infectious diseases. Islands states in Asia Pacific are prone to natural disasters and climate variations. Four Island states in the Pacific were looked at namely Fiji, Maldives, Nauru and Tuvalu. WASH Vulnerability criterion (WVC), Social Vulnerability Index and Economic Vulnerability index were calculated. In this study literature review was used risk assessment of contracting infectious diseases by referencing the risk equation. This was done by looking at the current sanitation system and how it maybe resulting a widespread of infectious diseases. The paper further looks at how sanitation may be weakened by natural disasters and hence increasing the risk of contracting infectious diseases. Of the four states Nauru had the highest *WVC* with a value of 0.082. The social vulnerability indices fluctuated throughout the years. A comparison was also made between vulnerabilities between urban and rural areas. There was a positive correlation between WVC and MCFURY using the Pearson correlation coefficient for three of the states except for Fiji. Data used was extracted from World Bank Data and UNDP. The results are used to propose strategies of improving disaster management to decrease vulnerability to infectious diseases. Rainwater harvesting is the primary source of safe drinking water in these areas. Ways of improving rainwater harvesting techniques are also suggested to maximize access to safe and affordable drinking water..

Keywords: Disaster management, sanitation, natural disasters, infectious diseases, Asia Pacific, climate changes

1. Introduction

Four island states namely Tuvalu, Nauru, Fiji and Maldives were looked at to determine the link between sanitation and infectious disease. Due to limited fresh water resources and susceptibility to normal climate variabilities, natural disasters and contamination from human settlements the islands

[1] South Africa, tel 00-27-46-603-8825, fax 00-27-46-603-7506

[2] Belmont Valley Road, Makhanda (Grahamstown), 6139, South Africa

have limited water supply (Falkland, 1999). This study looks at four Island States, which have different physical conditions such as rainfall pattern, frequency of natural disasters and type of the natural disasters. Natural events and human activities cause serious water scarcity in the Pacific Island states. Inter annual El Nino and La Nina cycles result in variable monthly and annual rainfall patterns (White and Falkland, 2010). Limited rainfall results in depletion of ground water and rainwater harvested necessitating the use of other water sources, which may be costly. Socio-economic conditions are also variable in these states. Each state will therefore be looked at individually. According to WHO 2008 about 88% of all diarrheal diseases are a result of use of inadequate sanitation, unsafe water and poor hygiene practices (Prüss-Üstün, A et al 2008). A study has shown that: "a reduction of 25 % (95% CI 9% -38%) in diarrheal cases can be observed when providing an improved water supply and 32% (95% CI 13% - 47%) when providing improved sanitation facilities" (Haller, Bartram and Hutton, 2008). A reduction of 33% (95% CI 24%- 41%) is achieved if both improved water supply and improved sanitation are used (Haller, Bartram and Hutton, 2008).

1.1. Nauru

Nauru relies on rainwater, imported water, shallow confined groundwater and desalination (Wallis, 2007). The annual rainfall in Nauru is variable, but has averaged 2,126 mm per year between 1916 and 1993 (Climate change profile: Nauru, 2013). Rainwater is collected from roofs into rainwater tanks. According to World Bank Data a total of 100% of the population in Nauru uses improved drinking water and 65.56% of the population has improved sanitation facilities in 2015. Concrete and steel tanks for rainwater harvesting which were constructed in Nauru have deteriorated and are now out of use (Wallis et al. 2007). The same has happened to guttering and rainwater tanks in houses. Fixing the deteriorated rainwater harvesting equipment or buying new equipment has been shown to be more expensive as compared to cost of delivering desalinated water by government trucks. (Wallis et al., 2007). More rainwater tanks were installed and the available ones were renovated. As a supplement to rain water harvesting, the government of Nauru provides 32 litres per person per day of uncontaminated water (WHO, 2008) (MDG taskforce and UNDP Multi-country Office, 2012). Nauru has no wastewater treatment so sewages and wastewater are discharged in the sea or disposed of in homes (WHO, 2008). In homes, sanitation is mostly cesspit allowing the wastewater to infiltrate the porous ground (WHO, 2008). Poor sanitation coupled with limited water gives rise to infectious diseases. Nauru had the highest rate of diarrhea in the pacific region (MDG taskforce and UNDP Multi-country Office, 2012). Nauru had 1015 cases of diarrhea per 1200 people in 2002 (WHO Western Pacific Regional report and SOPAC, 2008).

1.2. Tuvalu

The primary source of water in Tuvalu is rainwater harvesting. The average rainfall was 265.5 mm/month between 2008 and 2009 (Tuvalu MDG report, 2011). Tuvalu experiences droughts for up to 3 to 4 months a year (SOPAC, 2007). Poorly constructed and maintained household roof gutters result in quick depletion of water supply (Tuvalu MDG report, 2011). In the 1980s, there was provision of Ferro-cement storage tanks, used to collect rainwater (SOPAC, 2007). In 2009, the government distributed the 10,000 litre water tanks in every household in the capital island Funafuti (Tuvalu MDG report, 2011). Between 58 and 82 % of water storage containers in Tuvalu were positive for faecal contamination using the hydrogen-sulphide test (Tuvalu MDG report, 2011). Groundwater is available in the form of wells and can be used mainly for feeding livestock, flushing toilets, washing clothes and bathing (SOPAC, 2007). Because of widespread use of pit latrines and septic tanks, groundwater is contaminated, and this results in diseases, i.e. as demonstrated through 1,809 reported cases of diarrhoea caused by Vibrio cholerae in Tuvalu in 1990 (SOPAC, 2007). Bottled water is available through imports from Fiji but is too costly for the majority of the population (SOPAC, 2007). Desalination is used for drinking water provision only during severe water shortages due to the associated cost (SOPAC, 2007). The cost to refill household water tanks is 13.50 AUD per 500 litres (Tuvalu MDG report, 2011).

1.3. Maldives

Maldives consists of 1900 tiny coral islands (Ibrahim & Bari, 2002). The islands rely on rainwater, groundwater and desalination (Ebrahim, 2011). A study by Bailey & Khalil, 2015 indicated that the average thickness of water lens is 4.6 m, groundwater volume is 1,300 litres and this results to a per capita safe yield of 300l/day. Two thirds of the population lives on atolls (MDG Maldives, 2010) and they use rainwater for drinking while groundwater is used for other sanitation purposes (Ebrahim, 2011). Groundwater in atolls is contaminated by poorly constructed septic tanks as well as sewage and human wastes which are directly discharged into groundwater (MDG Maldives, 2010). The capital island of Male has piped water available to the population which is produced through desalination (Ebrahim, 2011). Male water is provided by the Male Water and Sewerage Company (MWSC) with a tariff of USD $1.43 per m3 for 0-100 litres and a fixed monthly charge of $1.95 per m3 (USAID, 2012). The tariffs are structured as increasing-block tariffs necessitating water rationing in order to pay less money. All the other Islands in Maldives use about 80-110 L per day and this usually depends on the type of toilet they use (Falkland, 2001). Majority of Maldives islands have poorly built septic tanks, and the tanks are corroded by hydrogen sulphide (Ebrahim, 2011). Waste is disposed in bushes or burnt within the households (MDG Maldives, 2010).

1.4. Fiji

Geographical location of Fiji makes it susceptible to natural disasters such as Tsunami, earthquakes, cyclones and floods. The disasters affect sanitation and water supply thus increasing pressure to already poor health conditions in the communities (Narsey Lal, 2009). According to EMDAT the international disaster database there was a drought in Fiji in September and October 2015 (Guha-Sapir, 2008). The drought affected 67,000 people in Fiji. From the years 2005-2019, EMDAT recorded 11 tropical cyclones, and the worst one was cyclone Winston in 2016 (Guha-Sapir, 2019). Cyclone Winston 540,558 people and a total death toll of 45 (Guha-Sapir, 2019). Inadequate sanitation and water supply promotes transmission of pathogens and this is worsened by natural disasters. A study by Sheel et al 2019 was aimed at evaluating the effectiveness of the Early Warning and Response System application by the WHO in detecting and controlling disease outbreaks after the cyclone. The success of the application showed a high level of resilience the public healthcare system in Fiji because of its ability to detect disease outbreaks. In the study, some WASH related diseases noted were acute watery diarrhea and acute bloody diarrhea. Acute watery diarrhea had frequency of 29.8 cases/100 people while acute bloody diarrhea had a frequency of 0.7 cases/100 people. This highlights the level of risk of infectious disease spread after a natural disaster. The risk in such events increases because of displacement of people, overcrowding in the few remaining shelters and poor access to safe drinking water. The risk for transmitting pathogens also increases due to pollution of the available groundwater reserves. Faecal contamination and littering of limited groundwater sources puts them out of use resulting in decrease of water supply (SOPAC Miscellaneous Report 674, 2008). The faecal oral route results in spread of diseases such as diarrheal diseases, polio and hepatitis A. After a Hepatitis A outbreak in an area situated in Fiji's capital island was noted in 2013, a study was carried out to identify potential sources of the infection (Getahun, 2015). Samples of drinking water were collected from all the water sources. Although the town had access to treated water from the Fiji Water Authority, the affected community used water from a dam. The water collected from the dam for assessment was found to be faecally contaminated, with the concentrations of Escherichia coli ranging from 5 to 43 cells per 100 mL (Getahun, 2015). The WHO bacteriological quality of drinking water guidelines states that all water required for drinking purposes must contain less 0 cells of Escherichia coli per 100 mL (Havelaar et al., 2001) (WHO, 2011).

Rural to urban migration continue increasing in Fiji thus increasing demand for land and housing in urban areas this results in people living in squatter camps and other informal settlements (Narsey Lal, 2009). According to statistics 7% of population in Fiji is living in 200 squatter settlements (Narsey Lal, 2009). Squatter camps have no piped water and lack access to health services. Because of insufficient water supply there is likeliness of poor hygiene in the squatter camps and informal settlements. This increases transmission of pathogens.

1.5. Context of the study

Rapid urbanization in Asia Pacific islands has greatly affected water quality as resulted in pollution of water bodies. This is a result of poor wastewater treatment, where wastewater is generally discharged into water systems without sufficient treatment (Unescap.org, 2016). In some places sanitation is very poor. In 2002, 871 cases of acute diarrhea per 1000 people were reported in the Asia Pacific region (WHO Western Pacific Regional and SOPAC, 2008). The forms of diarrheal diseases included cholera, typhoid and dysentery (WHO Western Pacific Region and SOPAC, 2008). The incidence of diarrhoea in Fiji, Nauru and Tuvalu in 2002 was 772, 1015 and 785 respectively per 1000 people (WHO Western Pacific Regional and SOPAC, 2008).

According to UN-WATER (2014), the Asia Pacific region often suffers from disasters and has one of the highest disaster vulnerabilities in the world. Climate change may result in droughts or floods, these may result in scarcity or deterioration of water quality, thus increasing water related epidemics (Narsey Lal, 2009). The El Nino phenomenon has caused various types of disasters, e.g. a drought in Fiji between 1997 and 1998 (Narsey Lal, 2009). The drought resulted in a greater number of people requiring government water delivery (WHO, 2016). During a natural disaster a number of people die but its effects do not end there. After natural disasters, human populations are displaced, and sanitation infrastructure is often destroyed; and available volumes of drinking water decrease. An example is the 2004 Tsunami disaster which hit Maldives with an estimated damage which was worth 62% of the GDP (MDG Maldives, 2010) and 13,000 people homeless (Guha-Sapir, 2008). Droughts and flooding as an example of natural disasters increase vulnerability to infectious diseases (WHO, 2016). This study looks at risk of contracting infectious diseases because of poor sanitation. It provides a systemic risk assessment and highlights vulnerability assessment in terms of sanitation in the four island states of Asia Pacific region. The paper goes on to look at how natural disasters contribute to weakening the sanitation system and thus increasing vulnerability to infectious diseases.

2. Methodology

In this study, Scopus and Google Scholar search engines were used to access journal articles, reports and books using a combination of the key words: disaster management, sanitation, natural disasters, infectious diseases, Asia Pacific, climate change, Nauru, Tuvalu, Maldives and Fiji. United Nations, World Health Organisation websites and World Bank data sites were used as reliable sources for data used to quantify vulnerability. Data used was from the year 2005 to 2015. A literature review was done. This was then followed by gathering points for each of the parameters of the risk equation. This allowed assessment of the progress made in increasing the number of people with access to clean safe water and basic sanitation. EM-DAT the international disaster database was used to access the most prevalent natural disasters in the Pacific Island States in question. Vulnerability was calculated with respect to WASH, social and economic vulnerabilities.

2.1. Risk assessment

Risk assessment involves qualitative and quantitative assessment of risk using suitable risk equations found in the literature. By definition risk is the possibility of encountering danger or loss as a result of encountering a hazard (Schneiderbauer, 2004). This research looks at risk of contracting a sanitation related epidemic as a result of being exposed to poor sanitation where this is worsened by natural and manmade disasters. According to Chiang (2003) and Smith (2001) disaster risk can be calculated using the equation:

$$R = Haz \times Vul \times Exp \qquad \text{[Equation 1]}$$

Where R is the disaster risk, Haz is the hazard, which is a threat on wellbeing of people and can cause loss of life, injury or disruption of property. Vul is vulnerability and it looks at the social, political, health and economic processes of a disaster prone area, and it measures the ability of a population to cope, anticipate and recover from a disaster. Exp is exposure of population or property exposed to the negative effects. In this research property will be the sanitation system or equipment. Exposure also looks at exposure of population to the causative agent of the infectious disease.

The above equation can be further modified by Tandlich et al (2013) to include preparedness and resilience which are inversely proportional to the risk. The equation is as follows

R=(Vul x Exp x Haz)/Prep =(Exp x Haz)/Res [Equation 2]

The definition for R, Vul, Exp, Haz in equation 2 are the same as the ones in equation 1 above. Prep represents preparedness which involves "activities and measures taken in advance to ensure anticipation, effective response and recovery to impacts of a hazard" (UNISDR, 2009). Res is Resilience and is the ability of a system which has been affected by a hazard, to resist, adapt and recover from the effects of a hazard within a specific time period in an efficient manner (Ferrier, 2003).

2.2 Vulnerability assessment.

Vulnerability was calculated with respect to social, WASH (water, sanitation and hygiene) and economic processes of the Island State. WASH Vulnerability criterion (which will be abbreviated as WVC in the following text) is based on the population of the Island States with improved water resources and improved sanitation facilities. Data used for improved water and sanitation was extracted from the World Bank Data. Data used was for the years 2005 to 2015 and will be given for the total population (represented by subscript T), urban population (represented by subscript U) and rural population (represented by subscript R), with access to improved water resources and sanitation facilities. The data used showed the trend in number of people using improved sanitation and with access to clean water in the time periods. The trends will be used to compare between rural and urban populations. Population of the island states with access to improved water resources will use the abbreviation AIWR and the population with access to improved sanitation facilities will be AISF. AIWR and AISF are given in percentages. To come up with dimensionless values of AIWR and AISF, they were converted to fractions. The following equation developed by Tandlich et.al. (2018) was used to assess WVC. The equation is still under development.

$$WVC = \log \left[100 \text{ x} \frac{1}{0.5 \text{ x } (\text{AIWR}+\text{AISF})}\right] \quad \text{[Equation 3]}$$

The equation shows that WVC is inversely proportional to the average value of AIWR and AISF. The equation can be simplified as shown below.

$$WVC = \log \frac{200}{\text{AIWR}+\text{AISF}} \quad \text{[Equation 4]}$$

Microsoft excel 2016 was used to do the calculations.

2.3 Social Vulnerability Indicator (André, 2012)

Social vulnerability indicator is abbreviated as SVI in the following text. SVI is based on the economic status of the island states, population growth rate, percentage of population living in urban areas and also human development of the Island states. Percentage of population living in urban areas is converted to a dimensionless fraction and this becomes the parameter FUP. That is fraction of population living in urban areas. The variables play a role in provision of improved sanitation facilities and access to improved water resources. Data for population growth rate was extracted from WorldBank(b), 2017. GDP data was from WorldBank(c), 2017). Human Development Index for all Island States was from UNDP, 2016. The equation below is used to quantify social vulnerability.

$$SVI = \frac{FUP\ x\ Cp}{HDI\ x\ Log\ (GDP)}$$ [Equation 5]

Where:

FUP is fraction of urban population

Cp is population growth rate and is presented as a fraction to obtain a dimensionless figure.

HDI is the Human development index ($year^{0.667}$)

GDP is gross domestic product per capita

2.4 Economic Vulnerability indicator (André, 2012)

Economic vulnerability indicator is abbreviated as EVI and takes into account the economic status of the island states, population growth rate, percentage of population living in urban and rural areas and human development index. EVI can be quantified using the equation below.

$$EVI = \frac{FUP\ x\ log(GDP)}{Cp\ x\ HDI}$$ [Equation 6]

The definition of *FUP, GDP, Cp* and *HDI* are the same as in equation 5 above. Microsoft Excel 2013 was used to perform calculations for EVI and SVI.

2.5 Mortality of children under five years of age (MCFURY)

The MCFURY values are given per 1000 live births. The values are used to determine the link between WVC and diarrhoeal disease. This is because lack of access to clean water, basic sanitation and poor hygiene results in spread of diarrhoeal diseases causing about 842,000 deaths annually (WHO, 2014) especially in children under 5 years of age.

3. Results and discussion

The results shown below in table form represent risk assessment for all four Island states in question for each parameter in the risk equation. This is summarised in the table below.

Fiji

Vulnerability		
Vulnerability	Comment	Reference
People staying in low lying areas.	- Such areas are greatly affected by floods.	(Narsey Lal, 2009)
Poor town planning and fully silted drainage system.	- Poorly planned towns have poor sanitation systems and if an epidemic strikes the town it will quickly spread. - Fully silted drainage systems means that floodwater stays on the ground longer and this increases risk of contamination of ground water sources. - Poor maintenance of drainage infrastructure.	(SOPAC Miscellaneous Report 674, 2008)

Economic vulnerability	- Insufficient funds for disaster risk management. - Government agencies still lack dedicated budget for risk reduction and prevention. This shows that in the case of a natural disaster which affects access to water and there is damage to sanitation system, the Island state will take time to recover.	(SOPAC Miscellaneous Report 674, 2008)
Environmental vulnerability	- Contamination of water sources increases vulnerability to contracting water borne infectious diseases. - 2008 there was an outbreak of typhoid in Fiji due to contamination of water.	(SOPAC Miscellaneous Report 674, 2008)
Poverty: -	- The poorest in a community are affected more because of increased disaster vulnerability in comparison to communities with a higher level of human development. The percentage of the Fijian population, which has been documented to live below the poverty line, has been reported to be at around 31%. - Human development index (HDI) for Fiji 0.736. This indicates that Fiji has medium human development. HDI measures human development with respect to three important dimensions, which are life expectancy, education and standard of living. Level of development is inversely proportional to vulnerability. The higher the HDI the lower the vulnerability. - Increase in poverty increases severity of disaster outcomes. - Low household income families have no water security or safe sanitation and may often have little education. - Literacy rate as at 2010 is 95.7% - Diminished resources to procure clean water, sanitation and necessary medicine.	(Narsey Lal, 2009) (Fiji - Population below poverty line - Historical Data Graphs per Year, 2016) (Fiji - Human Development Index, 2016) (The Pacific Islands Forum Secretariat , 2012) (Narsey & Waqavonovono, 2010) (Narsey Lal, 2009)

Hazards		
Hazard	Comments	Reference
Climate change	- May result in droughts or floods, these may result in scarcity or deterioration of water quality and thus increasing water related epidemics. According to EMDAT the international disaster database there was a drought in Fiji in September and October 2015. The drought affected 67,000 people in Fiji.	(Narsey Lal, 2009) (Guha-Sapir, 2008)

Drought	- 98 % of the population have access to improved drinking water and 83% have access to improved sanitation. - The sustainable development goal 6 focuses on ensuring access to water and sanitation for all. The target is to reach 100% of population with access to both improved drinking water and sanitation by 2030. - Inadequate sanitation and water supply promotes transmission of pathogens.	(The Pacific Islands Forum Secretariat , 2012) (UNDP Pacific Office in Fiji, 2016)
Pollution	- Faecal contamination and littering of limited groundwater sources puts them out of use resulting in decrease of water supply. - Pollution also increases risk of contracting infectious diseases.	(SOPAC Miscellaneous Report 674, 2008)
Geographic location of Fiji.	- Fiji is susceptible to natural disasters such as Tsunami, earthquakes and floods. The disasters affect sanitation and water supply thus increasing pressure to already poor health conditions in the communities.	(Narsey Lal, 2009)

Exposure		
Exposure	Comments	Reference
Rural to urban migration	- Migration increases demand for land and housing in urban areas this results in people living in squatter camps and other informal settlements. - 7% of population in Fiji is living in 200 squatter settlements. - Squatter camps have no piped water and lack access to health services. - Because of insufficient water supply there is likeliness of poor hygiene in the squatter camps and informal settlements. - This increases transmission of pathogens.	(Narsey Lal, 2009) (Narsey Lal, 2009)

Resilience		
Resilience	Comments	Reference
Community level	- Communities are receiving training in community multi hazard assessment. - Evacuation drills are being practiced. - Public education and awareness activities.	(Dobui, 2012)
Schools	- Disaster management is part of school curriculum.	(Dobui, 2012)

	- Schools have developed Disaster Management plans from internal customised risk assessment at sector levels.	
Government	- During emergency government departments redirects funds from existing budgets to emergency procurement. - Policies have been put to place by civil societies for poverty reduction. - Disaster and Risk Management is now included in sector policies and regulations of water, housing and waste water management. - Development of early warning systems. - Development of Tsunami procedures.	(Dobui, 2012)
International efforts	- Efforts being done to address climate change at the policy development level. - MDGs, National Adaptive Programme of Action from the UNFCC, the UN Directive on National Sustainable Development Strategy and National plans from the Hygo framework of action.	(Dobui, 2012)
Water quality management	- There is no set legislation for water quality, WHO guidelines are used	(Mirti & Davies, 2005)

Tuvalu

Vulnerability		
Type	Comment	Reference
Sanitation system	- Poorly constructed septic tanks have an impact on sanitation and hygiene and this increases vulnerability to contracting infectious diseases. - Flush toilets discharge into septic tanks which are poorly managed, poorly constructed and have no proper treatment. - At times greywater is disposed of on soak-away outside of dwellings, this poses a threat on groundwater in terms of pollution.	(SOPAC, 2007)
Climate changes	- Reliance on rainwater harvesting means that climate changes may increase community vulnerability because of compromised access to water during drought periods. - Various weather cycles such as EL Nino and La Nina may result in storms, cyclones, heavy rains and drought. - Storms and cyclones may disrupt the sanitation system.	(SOPAC, 2007)

Storage capacity of water	- Insufficient capacity and storage plus poor construction and maintenance of rainwater harvesting system means quick depletion of water and harvested water may be easily polluted. - Insufficient storage results in inadequate water for basic hygiene and flushing water borne toilets.	(SOPAC, 2007)
Waste disposal	- Waste disposal is poorly controlled and the disposal management is inadequate - Limited financial resources available to households to install and maintain environmentally sound wastewater treatment system. - Limited types of waste water treatments available to the community. - Over used dumping sites may pollute groundwater.	(SOPAC, 2007)
Poverty : human development index	- Low-income households in urban areas have no access to water, sanitation and wastewater management services. - Poverty may also result in insufficient access to education and health care services.	(SOPAC, 2007)
Community location	- People living close to water are more vulnerable to storm surges.	(Gerber, 2011)

Hazards		
Type	Comment	Reference
Poor hygiene	- Poor hygiene increases disease transmission by flies. - During periods of water scarcity where waterborne toilet systems cannot be used lagoon and ocean side beaches are used for defecation purposes.	(SOPAC, 2007)
Natural disasters	- Tuvalu lies in a region susceptible to cyclones. - It is also prone to other natural disasters such as storm surges, El Nino/ La Nina phenomena and droughts. - Quality of groundwater is worsened by natural disasters. - Contamination of rainwater tanks and ground water due to saline intrusion after storm surges. The most recent storm was in 2015 and it affected 4613 people.	(Gerber, 2011) (Gerber, 2011) (Guha-Sapir, 2008)

Exposure		
Type	Comment	Reference
Sanitation threats	- Septic tanks over flowing contaminate adjacent lands and also contaminates groundwater. - This exposes these areas to diarrhoea causing micro-organisms.	(Gerber, 2011)
Population growth	- Increases pressure on resources. - Disease outbreaks may increase as diseases can quickly spread in over populated areas. Health expenditure is 9.9% of GDP - Traditional coping methods to shortage of water are becoming mismatched with growing population	(Roberts, et al. 2011)
Pollution	- Household rainwater harvesting system may be polluted by animal droppings and dust - Pollution of groundwater from solid wastes and human excreta increases exposure to disease causing organisms especially in children	(SOPAC, 2007) (SOPAC, 2007)

Nauru

Vulnerability		
Type	Comment	Reference
Inadequate supply of fresh water.	- This has a detrimental effect on health because it results in higher incidence of waterborne diseases such as diarrhoea and typhoid.	(Climate change profile: Nauru, 2013)
Economic vulnerability	- Country's GDP is affected by natural disasters such as droughts and floods. - There is no allocated budget for risk reduction or prevention by the government.	(Climate change profile: Nauru, 2013) (Harris, 2012)
Absence of surface water on the island	- The limited groundwater on Nauru is often not suitable for human consumption due to sewage and domestic wastewater intrusion.	(WHO, 2008)
Poor waste management	- There is no waste treatment in Nauru and this gives rise to spread of infectious diseases.	(WHO, 2008)

Hazards		
Type	Comment	Reference
Climate changes	- Dependency on rainwater harvesting results in water shortages when there is a drought.	(Climate change profile: Nauru, 2013)

	- Droughts may last for as long as 3 years. - There is lack of highly trained personnel to manage effects of climate change.	
Congested living	- Housing and building based on ownership of land plots result in congestion in these areas. - If an epidemic strikes it can easily spread within the homes.	(MDG taskforce and UNDP Multi-country Office, 2012)
Poor maintenance of rainwater harvesting equipment	- Deterioration of rainwater harvesting equipment as a result of an economic downturn resulting in failure of households to repair their rainwater harvesting equipment. This causes faster depletion of household water when there is a longer period of dry spell - This has decreased water supply in households.	(Wallis, 2007) (MDG taskforce and UNDP Multi-country Office, 2012)
Geographical location	- The location of Nauru exposes it to extreme weather patterns that range from storm surges to prolonged drought periods.	(Wallis, 2007)

Exposure		
Type	Comment	Reference
Current Population	- Population of Nauru stood at 9976 in 2010. - Of this population 25.1% is below basic poverty line. This is a population of people living on less than USD $1.90 a day. - There is a link between poverty and lack of adequate access to basic sanitation and clean water. - The human development index is (HDI) 0.7. This is a measure of the degree of development. A score of 0.7 indicates that Nauru has medium development.	(WPRO Nauru, 2016) (MDG taskforce and UNDP Multi-country Office, 2012)

Resilience		
Type	Comment	Reference
Government interventions	- Implementation of policies that strengthen Disaster Risk Management through establishment of National Disaster Risk Management Office. Further efforts included preparation and finalising the text of a National Disaster Risk Management Plan.	(Harris, 2012)
Community level	- Community awareness programs on climate change adaptation and Disaster Risk Management. - The awareness programs help to enhance	(Harris, 2012)

	community awareness and resilience to impacts of all disasters.	

Maldives

Vulnerability		
Type	Comment	Reference
High population densities	- High population density results in over extraction of groundwater and also increases pollution of groundwater. Maldives has a population density of 1391,64 people per km^2 in 2016. High population density leads to a faster spread of infectious diseases within the dense population. - Over extraction of groundwater results in saline intrusion of the groundwater. - Some places are densely populated to the extent that there is insufficient space for rainwater storage tank.	(Ebrahim, 2011) (Population density in Maldives, 2016) (Ebrahim, 2011)
Economic factors	- Insufficient funds to improve sanitation at community level. - According to primary household data survey data from the World bank 7.26% of the population in Maldives live on less than \$1.90 a day in 2009	(Ebrahim, 2011)

Hazards		
Type	Comment	Reference
Poorly maintained water tanks	- Tanks are poorly built and are suffering from corrosion due to H_2S. - Tanks are desludged infrequently.	(Ebrahim, 2011)
Poor sanitation system	- Septic tank leakage contaminates groundwater. - Groundwater is used for cooking and drinking when rainwater is scarce. - This is contributing factor to heightened incidence of diarrhoea and infectious diseases.	(Ebrahim, 2011)
Natural disasters	- In 2004 Maldives was affected by an Indian ocean Tsunami. This resulted in saline intrusion of fresh water lens and ground water. - Sea-level rises also result in saline intrusion.	(MDG Maldives, 2010) (Bailey & Khalil, 2015)

Resilience		
Type	Comment	Reference
Government interventions in densely populated areas.	- Government of the Maldives focused its efforts on densely populated areas and built sewage systems in order to minimise pollution. - Rainwater storage tanks were given out freely in these communities. - Desalination plants were built in such areas.	(Ebrahim, 2011)

From the risk assessment it can be noted that the Island states have both similar and different characteristics with respect to the parameters of the risk equation. In the four island states, the most common hazards are climate change and natural disasters. These hazards result to depletion of water resources and this hence increases the number of people exposed to disease-causing microorganisms. Geographical location of the Island states increases the risk of extreme climatic events where drought is the major issue according to the risk assessment. Poor town planning characterized by poorly constructed septic tanks, poor waste management and poorly maintained water tanks is a common issue Fiji, Tuvalu and Maldives. It has been shown that community participation and poverty alleviation practices are important in planning and implementing water supply and sanitation programs (Crennan, 2005). Poverty is listed as one of the vulnerabilities of the Pacific islands as shown in the results above. Poor households are more likely to experience greater effect of natural disasters. Some of such households are built in informal settlements were they have little or no sanitation equipment, the risk of spread of infectious diseases increases. Rural to urban migration results in high population densities and rise in informal settlement is particularly seen in Fiji and Maldives. Poor maintenance of sanitation equipment in all four Island states greatly increases risk of contracting infectious waterborne diseases. In general limited ground water, overpopulation and pressure on available natural resources, lack of sufficient financial support from either government or international organizations, climate change and natural disasters are some of the common elements in the four Island states which result in increased risk of spread of waterborne infections.

To better understand the consequences of limited access to basic water, sanitation and hygiene and the link to public health, mortality rate of children under the ages of 5 years can be referred to. Nauru had the highest infant mortality rate of the four Island states, with a mortality rate of 35 per 1000 live births. According to WHO 2018 diarrhea accounts for 8% of death in children below 5 years of age. (WHO, Levels & Trends in Child Mortality , 2018). This is supported by the fact that Nauru had the highest prevalence of diarrheal diseases in the whole of Asia and the Pacific (WHO Western Pacific Regional and SOPAC, 2008). Under-five mortality rate of Fiji has shown a slight increase since 2000, and in 2015 it was 24.6 per 1000 births. Tuvalu and Maldives have had a decrease in infant mortality since 2000, with Maldives having an infant mortality rate of 8 per 1000 live birth in 2015. Despite the decrease of infant mortality rate in Tuvalu (26.6 per 1000 live births), the rate is still quite high as compared to Fiji and Maldives. Infant mortality rate data was extracted from the World Bank Data database. Data for mortality rate attributed to poor access to clean water, sanitation and lack of hygiene in 2016 showed that Fiji had a higher mortality rate as compared to Maldives with 2.9 and 0.3 per 100 000 people respectively.

The four Island states progressed significantly in achieving the 2015 Millennium Development Goal (MDG) 7 which aimed to ensure environmental sustainability and one of its targets was to half the proportion of people without access to safe drinking water and basic sanitation by 2015 (Lenton & Wright, 2005). WVC has a minimum value of 0 which is attained when both AIWR and AISF are 100%. The value of WVC goes towards 1 as AIWR and AISF decrease and towards 0 as AIWR and AISF increase. Data used was extracted from Data.worldbank.org. (2019 (a-f)).

Fiji WVC

Year	Rural population				Urban Population				Total Population			
	AIWR (%)	AISF (%)	WVC (dimensionless)		AIWR (%)	AISF (%)	WVC (dimensionless)		AIWR (%)	AISF (%)	WVC (dimensionless)	MCFURRY
2005	90,2344	76,36389	0,079359		98,67012	92,25777	0,020161		94,44138	84,29033	0,048828	23,1
2006	90,095	78,24622	0,07484		98,59394	92,64189	0,019461		94,36691	85,48206	0,046122	23,4
2007	89,95561	80,12855	0,070366		98,51777	93,026	0,018762		94,29294	86,66201	0,04346	23,7
2008	89,81621	82,01088	0,065938		98,44159	93,41012	0,018064		94,21955	87,83031	0,04084	23,9
2009	89,67681	83,89321	0,061555		98,36541	93,79424	0,017368		94,14623	88,9863	0,038265	24
2010	89,53741	85,77554	0,057216		98,28924	94,17835	0,016672		94,07331	90,13055	0,035731	24
2011	89,39802	87,65786	0,05292		98,21306	94,56247	0,015978		94,00071	91,26303	0,03324	24
2012	89,25862	89,54019	0,048665		98,13689	94,94659	0,015285		93,92823	92,38374	0,030789	24
2013	89,11922	91,42252	0,044452		98,06071	95,3307	0,014593		93,85607	93,49292	0,028379	24,1
2014	88,97982	93,30485	0,04028		97,98454	95,71482	0,013902		93,7842	94,59066	0,026007	24,3
2015	88,84042	95,18718	0,036147		97,90836	96,09894	0,013212		93,71245	95,67705	0,023674	24,6

Table 1Fiji WVC Data

The WVC_T has decreased throughout the years between 2005- 2015. From the results there was a notable difference between WVC_U and WVC_R, with the rural areas being more vulnerable. Between 2005-2015, EMDAT recorded 13 natural disasters, one drought, six floods and six tropical cyclones. Although WVC and AISF of both rural and urban areas increased, there was a notable decrease in AIWR in both places. A logical reasoning behind this observation would be the fact that both floods and storms contaminate groundwater reserves hence the water becomes of poor quality. Table 5 shows the SVI and EVI of Fiji. From 2005 to 2009, the SVI increased from 0,000311 to 0,000761 and then it decreased there after until 2014 where it was 0,000518. In 2015 there was an increase in urban population thus increasing the SVI to 0,000534. The Pearson correlation coefficient of Fiji for the relationship between MCFURY and WVC gives a strong negative value of -0.9293. The correlation between WVC and SV in Fiji is also a negative correlation with a value of -0.0763.

Maldives WVC

Year	Rural population				Urban Population				Total Population			
	AIWR (%)	AISF (%)	WVC (dimensionless)		AIWR (%)	AISF (%)	WVC (dimensionless)		AIWR (%)	AISF (%)	WVC (dimensionless)	MCFURRY
2005	92,94112	84,16231	0,052803		97,02801197	94,31992	0,019206		94,32044	87,5905	0,041171	22,6
2006	94,54384	86,70193	0,042762		96,80792834	94,09063	0,020227		95,33704	89,29048	0,034734	20
20	96,1	89,2	0,03294		96,587	93,8	0,02125		96,3	90,9	0,02866	17,8

07	4657	4154	8		84472	6135	1		0676	1867	5	
2008	97,74929	91,78115	0,023351		96,36776109	93,63206	0,022277		97,23049	92,47622	0,022947	16
2009	99,35202	94,32076	0,013961		96,14767746	93,40277	0,023305		98,10934	93,96476	0,017561	14,4
2010	99,7	96,86037	0,007534		95,92759384	93,17349	0,024336		98,19164	95,38621	0,014174	13,1
2011	99,7	98,31401	0,004334		95,70751021	92,9442	0,025369		98,05673	96,10385	0,012869	11,9
2012	99,7	98,31401	0,004334		95,70751021	92,9442	0,025369		98,01106	96,04242	0,013109	10,8
2013	99,7	98,31401	0,004334		95,70751021	92,9442	0,025369		97,96662	95,98266	0,013342	10
2014	99,7	98,31401	0,004334		95,70751021	92,9442	0,025369		97,92358	95,92477	0,013568	9,3
2015	99,7	98,31401	0,004334		95,70751021	92,9442	0,025369		97,88198	95,86882	0,013786	8,8

Table 2.WVC Maldives

Maldives has shown a tremendous decrease in WVC_R since 2010 when there was a notable improvement in both $AIWR_R$ and $AISF_R$. However, the urban population at the same time seemed to be facing challenges in terms of $AIWR_U$ and $AISF_U$. This resulted into an increase in WVC_U. Such an observation will necessitate investigation of factors which may have influenced the decrease in $AIWR_U$ and $AISF_U$, one of which could be the level of rural to urban migration and formation of shanty towns and informal urban settlements. The risk assessment showed that the population density of Maldives is high with 1391.64 people/km^2(Population density Maldives). Another factor could be that Maldives may have experienced a natural or manmade disaster which may have disrupted the sanitation system. Floods in 2007 affected 1 649 people as recorded by EMDAT. In 2011, there was an outbreak of Dengue fever in Maldives. Dengue fever is a vector borne disease spread by mosquitoes. This was a clear indication of increase in breeding ground for mosquitoes. The WHO noted this as an environmental health emergency and advised members of the public to cover their drinking water containers in order to prevent these containers from becoming breeding areas for mosquitoes (World Health Organization, 2019). The Pearson correlation coefficient of Maldives for the values of MCFURY and WVC gives a strong positive correlation of 0.9569. this means that there is an increase in MCFURY as WVC increases.

Nauru WVC

Year	Urban Population				Total Population			
	AIWR (%)	AISF (%)	WVC (dimensionless)		AIWR (%)	AISF(%)	WVC (dimensionless)	MCFURRY
2005	97,07737	65,66108	0,08954		97,07737	65,6610812	0,08954	38,5
2006	97,47138	65,65289	0,088511		97,47138	65,65288685	0,088511	38,6
2007	97,8654	65,64469	0,087485		97,8654	65,64469251	0,087485	38,9
2008	98,25941	65,6365	0,086462		98,25941	65,63649816	0,086462	39,2
2009	98,65342	65,6283	0,085441		98,65342	65,62830381	0,085441	39,2
201	99,0474	65,6201	0,084422		99,0474	65,6201094	0,084422	38,8

0	3	1			3	7		
2011	99,44145	65,61192	0,083406		99,44145	65,61191512	0,083406	38,3
2012	99,83546	65,60372	0,082392		99,83546	65,60372077	0,082392	37,6
2013	100	65,59553	0,081981		100	65,59552643	0,081981	36,8
2014	100	65,59553	0,081981		100	65,59552643	0,081981	35,9
2015	100	65,59553	0,081981		100	65,59552643	0,081981	35

Table 3:Nauru WVC

Nauru does not have a rural population. The $AISF_T$ in Nauru is lower than that of the other Island States in question. This also explains the high WVC in Nauru. The Pearson correlation coefficient for the relationship between WVC and MCFURY is 0.7058. This entails that increase in WVC results in increase in MCFURY value. Although the MCFURY value has improved with increase in AIWR, it still is higher than that of the other island states in question. The data for Nauru shows that AISF is largely contributing to WVC as can be seen the AISF is deteriorating while AIWR has reached the100% goal.

Tuvalu WVC

Year	Rural population				Urban Population				Total Population			
	AIWR(%)	AISF (%)	WVC (dimensionless)		AIWR(%)	AISF (%)	WVC (dimensionless)		AIWR (%)	AISF (%)	WVC (dimensionless)	MCFURRY
2005	97,52	79,53756	0,052916		98,32	94,02749	0,016943		97,91759	86,73891	0,034665	36,1
2006	97,66	80,99678	0,04901		98,46	93,76774	0,017214		98,06577	87,47434	0,032592	35,1
2007	97,8	82,456	0,04514		98,6	93,508	0,017485		98,21394	88,17464	0,030611	34,1
2008	97,94	83,91522	0,041304		98,74	93,24826	0,017755		98,36212	88,8398	0,02872	33,1
2009	98,08	85,37444	0,037502		98,88	92,98851	0,018026		98,51026	89,46944	0,026919	32,2
2010	98,22	86,83366	0,033732		99,02	92,72877	0,018297		98,65837	90,06394	0,025207	31,1
2011	98,36	88,29289	0,029995		99,16	92,46902	0,018569		98,80646	90,62346	0,023581	30,1
2012	98,5	89,75211	0,02629		99,3	92,20928	0,01884		98,95452	91,14815	0,022042	29,2
2013	98,64	91,10201	0,022867		99,44	91,94953	0,019112		99,10251	91,592	0,020692	28,3
2014	98,78	90,99622	0,022788		99,58	91,68979	0,019384		99,25026	91,40391	0,020784	27,4
2015	98,78	90,99622	0,022788		99,58	91,68979	0,019384		99,25774	91,4104	0,020752	26,6

Table 4:Tuvalu WVC

In Tuvalu, WVC_R was decreasing throughout the years whilst that one for the urban areas increased. This is due to the notable decrease in $AISF_U$. EMDAT recorded two natural disasters during the period of the study. In 2011, there was a drought. Regardless of there being a drought, there was no negative effect on the WVC_R which had a percentage decrease of 11.08% between 2010 and 2011. The WVC_U however continued increasing optimally. In the year 2015 Tuvalu experienced a tropical cyclone. There is a strong correlation between WVC and MCFURRY for Tuvalu. This is shown by the Pearson correlation coefficient of 0.9837.

Economic and Social Vulnerabilities

Fiji

Year	% urban population	FUP (dimensionless)	% population growth rate	Cp (dimensionless)	HDI ($year^{0.667}$)	GDP (USD)	SVI ($year^{1.5}$ $\times USD^{-1}$)	EVI (USD $\times year^{1.5}$)
2005	49,871	0,49871	0,422274	0,004223	0,695	5433175597	0,000311	1654,275
2006	50,264	0,50264	0,678381	0,006784	0,698	5703838092	0,000501	1035,637
2007	50,657	0,50657	0,8905	0,008905	0,702	5805825232	0,000658	791,2069
2008	51,146	0,51146	1,016365	0,010164	0,703	5980851473	0,000756	699,8449
2009	51,658	0,51658	1,01776	0,010178	0,707	5942745747	0,000761	701,6891
2010	52,171	0,52171	0,932645	0,009326	0,711	6193060637	0,000699	770,3892
2011	52,683	0,52683	0,826392	0,008264	0,717	6493459112	0,000619	872,457
2012	53,196	0,53196	0,747986	0,00748	0,719	6711393973	0,000563	972,0066
2013	53,706	0,53706	0,697997	0,00698	0,727	7152482324	0,000523	1042,96
2014	54,216	0,54216	0,689997	0,0069	0,73	7696171793	0,000518	1064,118
2015	54,726	0,54726	0,713519	0,007135	0,738	8077505744	0,000534	1029,641

Table 5:Fiji SVI and EVI

Maldives

Year	% urban population	FUP (dimensionless)	% population growth rate	Cp (dimensionless)	HDI ($year^{0.667}$)	GDP (USD)	SVI ($year^{1.5}$ $\times USD^{-1}$)	EVI (USD ×year1.5)

2005	33,75	0,3375	2,674098	0,026741	0,631	2632179012	0,001518	188,4224
2006	34,794	0,34794	2,641722	0,026417	0,643	3421463547	0,001499	195,295
2007	35,2	0,352	2,622539	0,026225	0,651	3783471348	0,001481	197,4739
2008	35,61	0,3561	2,638145	0,026381	0,66	4223602968	0,001479	196,8615
2009	36,021	0,36021	2,701024	0,02701	0,66	3948042227	0,001536	193,9058
2010	36,434	0,36434	2,784556	0,027846	0,671	4286595181	0,00157	187,8235
2011	36,849	0,36849	2,871857	0,028719	0,682	4751030618	0,001604	182,058
2012	37,267	0,37267	2,908784	0,029088	0,688	4964043280	0,001625	180,5551
2013	37,685	0,37685	2,857264	0,028573	0,696	5418937313	0,001589	184,4575
2014	38,106	0,38106	2,69366	0,026937	0,705	5926158352	0,00149	196,1007
2015	38,529	0,38529	2,45727	0,024573	0,71	6162300887	0,001362	216,1961

Table 6:Maldives EVI and SVI

Economic and social vulnerabilities for Nauru and Tuvalu were not calculated because there were no values for HDI for these Island States as stated by UNDP (2018).

Conclusion

This study has attempted to summarize all the parameters of the risk equation in order to assess the risk of contracting infectious diseases in four pacific island states. WVC, SVI and EVI were calculated and used to assess level of vulnerability of the four Island States. This enabled assessment of vulnerability to negative effects of natural disasters on WASH as well as vulnerability to sanitation related epidemics. Some knowledge gaps have been identified, e.g. under-reporting of the incidence rates and causative agents of diarrhoea. Reports are only made when there is an outbreak or in very serious cases. There is not much information on causative microorganisms in diarrhoea cases. There is little knowledge of water quality in these areas. Generally, for all the Island States there is limited knowledge of groundwater quality. Definition of improved drinking water and improved sanitation is subject to interpretation. There is no set minimum standard of improved drinking water and sanitation. When it comes to natural disasters, the events which have never occurred before are considered non-existent and therefore there is lack of preparedness in the case that they do happen. The major limitation of the study was unavailability of data for certain parameters of the equations in the study.

Some cost-effective ways of improving domestic rainwater harvesting technique include use of bamboo to make the guttering system and also to make basket tanks for water storage. Ponds can be dug allowing runoff collection of water into the ponds. This necessitates filtration of water before it is used. One way is hanging a piece of cloth on the edge of the gutter as water enters into the tank. The rainwater tanks in these island states are not frequently desludged and this results in contamination of drinking water. Contamination of water is also increased by the fact that the first flash of rainwater is not removed maybe because the tanks may already have some water in them.

Boiling water from the rainwater storage tanks is not very common, therefore people should be educated about the importance of boiling water before drinking it. In conclusion, the points falling under each parameter of the risk equation can be addressed at either community level or by the government of each of the states in order to minimize incidence of infectious diseases. To improve on the above equation the "hygiene" part of WASH can be represented by percentage of population with access to basic handwashing facilities. As already established most water borne pathogens are spread through faecal oral route, therefore access to basic handwashing facilities reduces the transmission of the pathogens. Unavailability of Data is a major challenge in such calculations as already proven by the lack of HDI of Tuvalu and Nauru.

Acknowledgment

The authors would like to thank Rhodes University Sandida Imbewu for financial support of the scholarship for the first author for the attendance at the 2019 Annual TIEMS Conference.

References

1. Andre, G. (2012). Natural hazard mapping across the world: A comparative study between a social approach and an economic approach to vulnerability. Cybergeo: European Journal of Geography.
2. Aneley Getahun, E. R. (2015). Hepatitis A outbreak in Ba subdivision, Fiji,. Outbreak Investigation Report.
3. Climate Change profile :Nauru. (2013). Global Climate Change Alliance: pacific small island states project.
4. Crennan, L. (2005). Equitable management of water and sanitation in Pacific Island countries. SOPAC Technical Report 388
5. D. Guha-Sapir, R. B. (2008). EM-DAT: The CRED/OFDA International Disaster Database. Retrieved from EM-DAT:: http://www.emdat.be/
6. Data.worldbank.org. (2019a). People using at least basic sanitation services (% of population) | Data. [online] Available at: https://data.worldbank.org/indicator/SH.STA.BASS.ZS [Accessed 7 Jun. 2019].
7. Data.worldbank.org. (2019b). People using at least basic sanitation services, rural (% of rural population) | Data. [online] Available at: https://data.worldbank.org/indicator/SH.STA.BASS.RU.ZS [Accessed 7 Jun. 2019].
8. Data.worldbank.org. (2019c). People using at least basic sanitation services, urban (% of urban population) | Data. [online] Available at: https://data.worldbank.org/indicator/SH.STA.BASS.UR.ZS [Accessed 7 Jun. 2019].
9. Data.worldbank.org. (2019d). People using at least basic drinking water services (% of population) | Data. [online] Available at: https://data.worldbank.org/indicator/SH.H2O.BASW.ZS [Accessed 7 Jun. 2019].
10. Data.worldbank.org. (2019e). People using at least basic drinking water services, rural (% of rural population) | Data. [online] Available at: https://data.worldbank.org/indicator/SH.H2O.BASW.RU.ZS [Accessed 7 Jun. 2019].
11. Data.worldbank.org. (2019f). People using at least basic drinking water services, urban (% of urban population) | Data. [online] Available at: https://data.worldbank.org/indicator/SH.H2O.BASW.UR.ZS [Accessed 7 Jun. 2019].
12. Data.worldbank.org. (2019g). Urban population (% of total) | Data. [online] Available at: https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS [Accessed 7 Jun. 2019].
13. Dobui, P. (2012, september). National progress report on the implementation of the Hyogo Framework for Action (2011-2013) -Interim. National Progress Report 2011-2013.
14. EM-DAT: The Emergency Events Database - Université catholique de Louvain (UCLouvain) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium; 2019

15. Falkland, T. (1999). Water resources issues of small island developing states. Natural Resources Forum, 245-260.
16. Falkland, T. (2001). Report on Groundwater Investigations in Northern Development Region . Report for Ministry of Planning and National Development.
17. Federica Gerber, P. H. (2011). Case study: water quality, quantity and sanitation improvements as an adaptation to climate change, Tuvalu – a preliminary assessment. A background case study for IUCN's report, Climate Change Adaptation in the Pacific: Making Informed Choices, prepared for the Australian Department of Climate Change and Energy Efficiency (DCCEE), IUCN, . suva .
18. Fiji - Human Development Index. (2016). Retrieved from Knoema: https://knoema.com/atlas/Fiji/Human-Development-Index
19. Fiji - Population below poverty line - Historical Data Graphs per Year. (2016). Retrieved from Indexmundi.com: http://www.indexmundi.com/g/g.aspx?c=fj&v=69
20. Harris, R. (2012, October). National progress report on the implementation of the Hyogo Framework for Action (2011-2013) -Interim.
21. Haller, L., Bartram, J. and Hutton, G. (2008). Estimating the costs and health benefits of water and sanitation improvements at global level. Journal of water and health.
22. Havelaar, A., Blumenthal, U. J., M. Strauss, D., & Bartram, K. a. (2001). Water Quality: Guidelines, Standards and Health. World Health Organization (WHO).
23. Ibrahim, S., & Bari, R. M. (2002). Water resource management in Maldives with emphasis on desalination. Maldives Water and SanitationAuthority.
24. Laurence Haller, G. H. (2008). Estimating the cost and health benefits of water and sanitation improvements at a global level. Journal of Water and Health, 467- 480.
25. (2010). MDG Maldives. Male: Department of National Planning.
26. MDG taskforce and UNDP Multi-country Office. (2012). Nauru Progress Report(1990-2011). Nauru MDG report.
27. Mirti, A., & S.Davies. (2005). Drinking Water Quality in the Pacific Island Countries: Situation Analysis and Needs Assessment . SOPAC Joint Contribution Report 181.
28. National Integrated Water Resource Management Diagnostic Report. (2007, November). Sustainable Integrated Water Resources and Wastewater Management in Pacific Island Countries.
29. Narsey, W., & Waqavonovono, T. R. (2010). Poverty and Household Incomes in Fiji in 2008-09 . Suva.
30. Padma Narsey Lal, R. S. (2009). Relationship between natural disasters and poverty: a Fiji case study.
31. POPULATION DENSITY (PEOPLE PER SQ. KM) IN MALDIVES. (2016). Retrieved from Tradingeconomics.com: http://www.tradingeconomics.com/maldives/population-density-people
32. Prüss-Üstün, A. Bos, R., Gore, F, and Bartram, J. (2008) Safer water, better health: costs, benefits and sustainability of interventions to protect and promote health. World Health Organization, Geneva,
33. Roberts, G., Irava, W., Tuiketei, T., Nadakuitavuki, R., Otealagi, S., Singh, S., Pellny, M., Fong, M., Mohammed, J & Chang, O. (2011). The Fiji Islands Health System Review. Health Systems in Transition.
34. Schneiderbauer, S. a. (2004). Risk, Hazard and People's Vulnerability to Natural Hazards: a Review of Definitions, Concepts and Data
35. Shaheedha A Ebrahim, M. R. (2011). Water resources management in Maldives. Maldives Water and Sanitation Authority.
36. Sheel, M; Collins,J ; Kama,M; Nand, D; Faktaufon,D; Samuela,J Biaukula, V; Haskew,C; Flint,J; Roper,K; Merianos,A; Kirka, M.D & Nillesd, E. Evaluation of the early warning, alert and response system after Cyclone Winston, Fiji, 2016. Bull World Health Organ 2019;97:178–189C doi: http://dx.doi.org/10.2471/BLT.18.211409
37. Shuman, E. K. (2010). Global Climate Change and Infectious Diseases. The NEW ENGLAND JOURNAL of MEDICINE, 1061-1063.
38. SOPAC. (2007, November). Sustainable Integrated Water Resources and Wastewater Management for Tuvalu. National Integrated Water Resource.

39. SOPAC Miscellaneous Report 674. (2008). Progress Report (2007 – 2009) on the Implementation of the Hyogo Framework for Action for the Pacific Islands Region.
40. Tandlich, R. Angala, H., Vhiriri, E. P., Ngqwala, N. P., Srinivas, C. S. 2018. Disaster and health vulnerability assessment for the population in the Kingdom of Bhutan. In: Journal for Studies in Humanities and Social Sciences Vol. 7, no. 1, pp. 62-86.
41. Tandlich, R., & Srinivas, T. C. (2013). Gender aspects of disaster management in South Africa. J. Disaster Risk Studies, 5 (4).
42. The Pacific Islands Forum Secretariat . (2012). 2012 Pacific Regional MDG Tracking Report .
43. Tuvalu MDG report. (2011). Tuvalu Millenium Development Goals progress report. Funafuti, Tuvalu.(2011). Tuvalu: Millenium Development Goals Progress report. Funafuti: Seona Smiles,.
44. UNDP Pacific Office in Fiji. (2016). Retrieved from Goal 6 :clean water and sanitation: http://www.pacific.undp.org/content/pacific/en/home/post-2015/sdg-overview/goal-6.html
45. UNEP. (2002). Vital Water Graphics. Retrieved from United Nations Environment Programme: http://staging.unep.org/dewa/assessments/ecosystems/water/vitalwater/18.htm
46. Unescap.org. (2016). Statistical Yearbook for Asia and the Pacific 2011. Retrieved from Unescap.org: http://www.unescap.org/stat/data/syb2011/II-Environment/Water-availability-and-use.asp
47. United Nations Development Programme. Human development reports. Human development Data (1990- 2017). Available at http://hdr.undp.org/en/data# . Accessed 1 June 2019
48. United Nations Development Program (UNDP). Human Development Indices and Indicators. 2018 Statistical Update for Small Island Developing States. Available at: https://sustainabledevelopment.un.org/content/documents/27972UNDP_2018_Statistical_update_Briefing_note_SIDS.pdf (accessed on 1 June 2019)
49. UN-WATER. (2014, October 17). The United Nations inter-agency mechanism on all fresh water related issues including sanitation. Retrieved from UN water: http://www.unwater.org/statistics/statistics-detail/en/c/211785/
50. USAID. (2012). Maldives water and sewer tariffs: current framework and policies. Retrieved December 13, 2017, from http://pdf.usaid.gov/pdf_docs/PA00HQCQ.pdf
51. Wallis I, R. L. (2007, November). IWRM National Diagnostic Report – Nauru. National Integrated Water Resource Management Diagnostic Report.
52. Wallis, I., Russ, L., Debao, S., & Bryan. (2007, November). Sustainable Integrated Water Resources. National Integrated Water Resource Management Diagnostic Report: Nauru.
53. White, I. and Falkland, T. (2010). Management of freshwater lenses on small Pacific islands. Hydrogeology Journal, 18, pp.227-246.
54. WHO. (2008). Sanitation, hygiene and drinking-water in the Pacific island countries : converting commitment into action.
55. WHO. (2012). World Health Organisation. Retrieved from World Health Organisation: http://www.wpro.who.int/countries/nru/19_nru_2012.pdf
56. WHO, 2014. Preventing Diarrhoea through better water, sanitation and hygiene: Exposure and impacts in Low and Middle-Income countries., Switzerland
57. WHO. (2016). Retrieved from World Health Organization: http://www.who.int/hac/techguidance/preparedness/el_nino_2015_2016/en/
58. WHO. (2016). Retrieved from Who.int: http://www.who.int/water_sanitation_health/2005advocguide/en/index5.html
59. WHO. (2008). Sanitation, hygiene and drinking-water in the Pacific island countries : converting commitment into action.
60. WHO. (2011). Retrieved November 12, 2017, from http://apps.who.int/iris/bitstream/10665/44584/1/9789241548151_eng.pdf
61. WHO. (2012). World Health Organisation. Retrieved from World Health Organisation: http://www.wpro.who.int/countries/nru/19_nru_2012.pdf
62. WHO. (2016). Retrieved from World Health Organization: http://www.who.int/hac/techguidance/preparedness/el_nino_2015_2016/en/
63. WHO. (2016). Retrieved from Who.int: http://www.who.int/water_sanitation_health/2005advocguide/en/index5.html

64. WHO Western Pacific Regional and SOPAC. (2008). Sanitation, hygiene and drinking-water in the Pacific island countries : Converting commitment into action .
65. WHO(a). (2017, November 30). Global Health Observatory data repository. Retrieved December 12, 2017, from World Health Organisation: http://apps.who.int/gho/data/node.main.WSHSANITATION?lang=en
66. WHO(b). (2016, May 11). Retrieved November 15, 2017, from http://apps.who.int/gho/data/view.main.SDGWSHBOD392v
67. WHO(b). (2017, November 30). Basic and safely managed drinking water services Data by country. Retrieved December 11, 2017, from World Health Organisation: http://apps.who.int/gho/data/node.main.WSHWATER?lang=en
68. WorldBank(a). (2017). Water productivity, total (constant 2010 US$ GDP per cubic meter of total freshwater withdrawal). Retrieved December 14, 2017, from The World Bank : https://data.worldbank.org/indicator/ER.GDP.FWTL.M3.KD
69. WorldBank(b). (2017). Population growth (annual %). Retrieved November 22, 2017, from The World Bank: https://data.worldbank.org/indicator/SP.POP.GROW
70. WorldBank(c). (2017). GDP current (USD). Retrieved November 15, 2017, from The World Bank: https://data.worldbank.org/indicator/NY.GDP.MKTP.CD
71. World Health Organization. (2019). Where is the risk of dengue fever most acute and what should be done?. [online] Available at: https://www.who.int/water_sanitation_health/emergencies/qa/emergencies_qa13/en/ [Accessed 6 June 2019].
72. WPRO Nauru. (2016). Retrieved from World Health Organisation: http://www.wpro.who.int/countries/nru/en/ [Accessed 6 June 2019].