The Vulnerability of Health Infrastructure to the Impacts of Climate Change and Sea Level Rise in Small Island Countries in the South Pacific

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ABSTRACT: Anthropogenic climate change and related sea level rise will have a range of impacts on populations, particularly in the low lying Pacific island countries (PICs). One of these impacts will be on the health and well-being of people in these nations. In such cases, access to medical facilities is important. This research looks at the medical facilities currently located on 14 PICs and how climate change related impacts such as sea level rise may affect these facilities. The medical infrastructure in each country were located using information from a range of sources such as Ministry of Health (MoH) websites, World Health Organization, Doctors Assisting in South Pacific Islands (DAISI), Commonwealth Health Online, and Google Maps. A spatial analysis was undertaken to identify medical infrastructure located within 4 zones from the coastline of each country: 0 to 50 m, 50 to 100 m, 100 to 200 m, and 200 to 500 m. The findings indicate that 62% of all assessed medical facilities in the 14 PICs are located within 500 m of the coast. The low-lying coral atoll countries of Kiribati, Marshall Islands, Nauru, Palau, Tokelau, and Tuvalu will be highly affected as all medical facilities in these countries fall within 500 m of the coast. The results provide a baseline analysis of the threats posed by sea-level rise to existing critical medical infrastructure in the 14 PICs and could be useful for adaptive planning. These countries have limited financial and technical resources which will make adaptation challenging.

KEYWORDS: Climate change, health infrastructure, sea level rise, Pacific island countries

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Introduction

The Intergovernmental Panel on Climate Change (IPCC) fifth assessment report has clearly outlined the pace and impact of climate change in the 21st century.[1] An undeniable consequence of climate change is sea level rise.[2] Sea level rise will have wide-ranging impacts on the inhabitants of small island states in the South Pacific region.[3] This region has thousands of habitable islands scattered across one third of the Earth's surface and these can be grouped into 3 distinct regions of Melanesia, Micronesia, and Polynesia (Figure 1).

The region is home to 10.8 million people, 70% of whom live in Papua New Guinea while the rest live mostly on small islands.[4] These small islands have certain characteristics that make their inhabitants vulnerable to the impacts of sea level rise. They include island lithology that are predominantly volcanic, limestone, reef, or a combination of these 3; however, approximately 67% of the islands are of reef or sandy origin, and have a high ratio of shoreline to land area, are low-lying, and are spread out over a vast area of ocean.[5,6] Due to limitations of land area, the bulk of the population, major urban centers, and critical infrastructure are generally located in coastal areas.[7,8] Consequently, a much larger proportion of the land area and associated population and infrastructure are exposed to potential impacts of sea level rise and its related impacts such as coastal inundation, saltwater intrusion, and flooding compared with larger islands or landlocked countries. Furthermore, an indicative index of physical susceptibility to coastal erosion induced by climate change of 1779 islands in this region indicated that approximately 41% of the assessed islands fell into the high or very high susceptibility classes.[9] As such, "Pacific island countries and areas are among the most vulnerable in the world to the impacts of climate change due to the confluence of geographic, demographic, and socioeconomic factors, such as low elevation, small populations, and scarce resources."[10]

The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states with very high confidence that "the health of human populations is sensitive to shifts in weather patterns and other aspects of climate change."[11] These can be direct health impacts such as deaths and illness resulting from more intense heat waves, fires, floods and droughts and damage to health infrastructure and indirect impacts caused by changing patterns of disease vectors, respiratory illnesses caused by declining air quality, and reduced food production thereby resulting in poor nutrition.[12] Pacific island countries (PICs) are among the most vulnerable societies in the world to the health impacts of a changing climate.[13,14]

Temperature records in the Pacific region show a consistent warming trend (+0.08°C-0.20°C per decade) over the past 50 years with the magnitude of background warming since the mid-20th century being consistent with human-induced global warming although rainfall patterns in the region are more strongly influenced by natural climate variability.[15,16] Furthermore, data from 1993 to 2009 indicate sea level rise of up to 3 times the global average in the western Pacific.[15] The populations in this region are already experiencing rising sea levels and changes in the frequency and intensity of extreme climatic events.[17,18] Future projections for tropical cyclones for

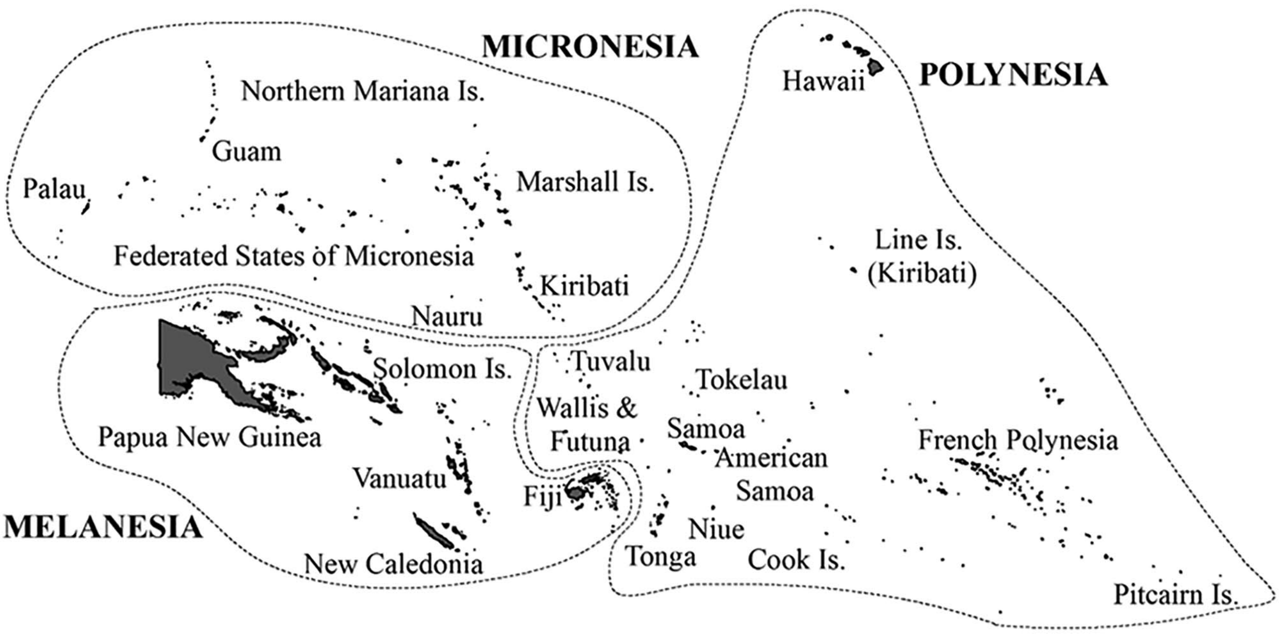

Figure 1. Map showing the countries located in the 3 distinct regions of Melanesia, Micronesia, and Polynesia in the Pacific Region.

the region report less frequent but more intense tropical cyclones by the end of the 21st century.[19] The most common health impacts from these events are injuries sustained during adverse weather events or vector-borne diseases resulting from hotter and wetter climates. Robust and efficient health care infrastructure will be necessary to cope with the impacts of climate change and in particular sea level rise. In an assessment of climate impacts on Pacific infrastructure, health infrastructure were identified as being "strongly" vulnerable to the following: storm surges, sea level rise, king tides, wave action, drought, prolonged rain, floods, and cyclonic winds.[20] Damage to health facilities caused by extreme weather events can disrupt essential health services when they are needed most urgently. For example, in Fiji tropical cyclone Winston damaged or destroyed 88 health clinics and medical facilities in 2016 and the total damage and losses to the health sector were estimated at approximately F$13.9 million.[21] Similarly, cyclone Pam in Vanuatu in 2014 caused a total of VT977 million worth of damage to the health sector.[22] A World Health Organization assessment of the impacts of climate change on human health in PICs identified "compromised access to health services, damage to health infrastructure, and additional strain on scarce resources" as a high priority climate-sensitive health risk in Pacific Island countries.[10]

The projected impacts of climate change on the health of Pacific island communities are unavoidable thus making adaptation essential. Informed and timely responses are crucial to improve communities' resilience to the challenges posed by climate change.[23] However, developing countries such as the PICs lack the financial resources to effectively adapt to the demands of a changing climate. Furthermore, the information required to accurately map and analyze the threats of sea level rise to medical infrastructure, such as elevation data, is not available for PICs. As a result, distance from the coast can be used as an alternative in assessments of vulnerability to sea level rise.[24] This study identifies the locations of critical medical infrastructure such as hospitals, medical centers, and nurse aid posts in 14 PICs. Their vulnerability to sea level rise is investigated through an assessment of their distance from the coast at 4 zones: 0 to 50 m, 50 to 100 m, 100 to 200 m and 200 to 500 m. The aim of this assessment is to provide a baseline analysis, which can inform early steps in adaptation efforts.

Methodology

The 14 countries (Table 1) included in this study were selected based on reliable publicly available data on medical infrastructure. The Ministry of Health (MoH) website (where available) of each country was used to locate a list of medical facilities in each country. Some countries, such as Fiji and Solomon Islands had reliable data available on their MoH web sites up to the level of nursing stations or nurse area posts that are located on remote islands. The Solomon Islands MoH website provided an interactive map indicating the location of each facility that allowed the latitude and longitude of each facility to be identified accurately. The Fijian MoH website had a list of medical facilities with an indicative map. This map, together with google maps, were used to identify the latitude and longitude of each medical facility. The location of some facilities could not be accurately identified and were left out of the analysis (only 180 out of 215 facilities were included in this analysis).

Countries such as Vanuatu had reliable data only up to provincial level on their MoH site. Therefore, data lower than the provincial level was not included for Vanuatu in this analysis. For countries where a dedicated MoH website could not be located, medical facilities were located through other websites such as World Health Organization, Doctors Assisting in

Table 1. Summary information about the 14 PICs included in this study.

COUNTRY	TOTAL LAND AREA[a] (KM^2)	COASTLINE[a] (KM)	POPULATION[a] (2020)	NUMBER OF MEDICAL FACILITIES[B]
Melanesia				
Fiji	18 274	1129	935 974	180
Solomon Islands	27 986	5313	685 097	303
Vanuatu	12 189	2528	298 333	7
Micronesia				
Federated States of Micronesia (FSM)	702	1036	102 436	7
Kiribati	811	1143	111 796	4
Marshall Islands	181	2172	77 917	2
Nauru	21	30	11 000 (2019)	2
Palau	459	1519	21 685	1
Polynesia				
Cook Islands	236	120	8574	2
Niue	260	64	2000 (2019)	1
Samoa	2821	403	203 774	12
Tokelau	12	101	1647 (2019)	3
Tonga	749	909	106 095	3
Tuvalu	26	24	11 342	2

[a]As per literature and The World Factbook (https://www.cia.gov/the-world-factbook/countries/).
[b]Includes major hospitals, community health centers, area health centers, rural health centers, and nurse aid posts.

South Pacific Islands (DAISI), Commonwealth Health Online, and Google Maps. A list of medical facilities was drawn up from this search and their latitudes and longitudes were noted in an Excel file. This was used to create a shapefile using ArcGIS Version 10.7.[25]

Coastlines for each country was obtained from the Global Self-Consistent, Hierarchical, High-Resolution Geography Database (GSHHG, 2017) Version 2.3.7.[26] These were overlain on the satellite basemap facility available in ArcGIS to check for any misalignments. All coastlines that needed correcting were adjusted. All coastlines and medical facilities shapefiles used in the analysis was projected to WGS_1984_World_Mercator before any analysis was undertaken.

ArcGIS software was used to create 4 zones at the following distances from the coastline: 0 to 50 m, 50 to 100 m, 100 to 200 m, and 200 to 500 m. These zones were chosen based on the geography and limited land area of the countries included in this study which meant that the critical medical infrastructure are generally located close to the coast.[5,7] A maximum zone width of 500 m was selected because anything larger would not be suitable for countries such as the Marshall Islands and Tuvalu as approximately 99% of the land area of the whole country falls within 500 m.[5] Although, countries such as Fiji, Tonga, Solomon Islands, and Vanuatu are comparatively large and high islands, the bulk of the population, major urban centers, and critical infrastructure are generally concentrated on narrow, low-lying areas fringing the mountains along the coast.[7] Therefore, a minimum of 50 m was used to ensure that all critical medical infrastructure could be included in the assessment. The number of medical facilities falling within each interval was extracted. This provided an assessment of the risk of sea level rise to the medical infrastructure of 14 PICs.

Elevation also plays an important role in vulnerability assessments and the inclusion of such data would have improved the accuracy of the assessment. However, elevation data at suitable accuracy are not available for most of the Pacific due to remoteness and the costs involved in collecting such data. Therefore, the horizontal distance from the coastline has been used as the single parameter of assessing vulnerability of health infrastructure to sea level rise in this study.

Results

The results of this analysis shows that 61.5% of all assessed medical facilities in the 14 PICs are located within 500 m of the coast. Of this, 12% fall within the 0 to 50 m zone, another 12% fall within the 50 to 100 m zone, 20% fall within the 100

Table 2. The number of medical facilities within each zone.

COUNTRY	0-50 M	50-100 M	100-200 M	200-500 M
Cook Islands	0	0	0	0
Fiji	18	9	26	20
Federated States of Micronesia (FSM)	0	1	0	4
Kiribati	0	2	1	1
Marshall Islands	0	1	1	0
Nauru	0	1	1	0
Niue	0	0	0	0
Palau	0	1	0	0
Samoa	3	2	1	3
Solomon Islands	37	46	76	60
Tokelau	1	2	0	0
Tonga	0	0	1	1
Tuvalu	2	0	0	0
Vanuatu	1	0	1	2
Total	62	65	108	91

to 200 m zone, and 17% fall within the 200 to 500 m zone. In Fiji, 41% of the medical facilities fall within 500 m of the coast while this figure is 75% for Samoa, 72% for the Solomon Islands, 67% for Tonga, and 57% for Vanuatu. On the other hand, all medical facilities identified for the Cook Islands and Niue fall beyond 500 m of the coast.

The results for FSM, Kiribati, Marshall Islands, Nauru, Palau, Tokelau, and Tuvalu are worth noting (Table 2). For 6 of the countries mentioned here (Kiribati, Marshall Islands, Nauru, Palau, Tokelau, and Tuvalu), all medical facilities fall within 500 m of the coast while 5 out of the 7 facilities identified for FSM fall within 500 m of the coast.

Some of the larger referral hospitals are included in the list of medical infrastructure located within 500 m of the coast. For example, the Princess Margaret Hospital in Tuvalu is the national reference hospital and major medical facility in the country. It is located within 50 m of the coast (Figure 2). Similarly, Tungaru Central Hospital, the largest referral hospital in Kiribati, is located within 100 m of the coast (Figure 3). This issue is not only restricted to the lower lying atoll countries such as Tuvalu and Kiribati but can also be observed in the larger PICs such as Solomon Islands where the National Referral Hospital in Honiara is located within 50 m of the coast (Figure 4). The medical facilities in the Solomon Islands are organized in 4 tiers: hospitals (9), area health centers (37), rural health clinics (98), and nurse aid posts (159). Specialist medical services such as acute psychiatric inpatient treatment, surgical and anaesthetic services, accidents and emergency services, laboratory diagnosis of communicable diseases, and coordination of disaster responses are only offered through the large hospitals. This analysis shows that 7 out of the 9 hospitals are located within 500 m of the coast. In Fiji, medical facilities are also organized in 4 tiers: divisional hospitals including 1 specialist psychiatric facility (5), sub-divisional hospitals including maternity units (19), health centers (80), and nursing stations (111). The major psychiatric facility falls within 500 m of the coast, however, the other major divisional hospitals are located beyond 500 m. This analysis also found that 8 of the sub-divisional hospitals are located within 500 m of the coast.

These results indicate that climate change and its associated impacts such as sea level rise and extreme weather events could cause damage to essential medical infrastructure in PICs, particularly low-lying atoll countries, during times when the need for access to medical services may be critical.

Discussion

Some of the highest priority climate-sensitive health risks in PICs include health impacts of extreme weather events, heat-related illness, waterborne, foodborne, and vector-borne diseases along with impacts on mental health and health systems. Another consequence of climate change is alterations in infectious disease transmission patterns due to changes in the geographic ranges of vectors.[27] This has implications for vector-borne diseases such as dengue fever and malaria, which are common in some of the PICs. Extreme weather events such as the flooding associated with cyclones can lead to outbreaks of not only dengue fever but also diarrhoeal disease.[14]

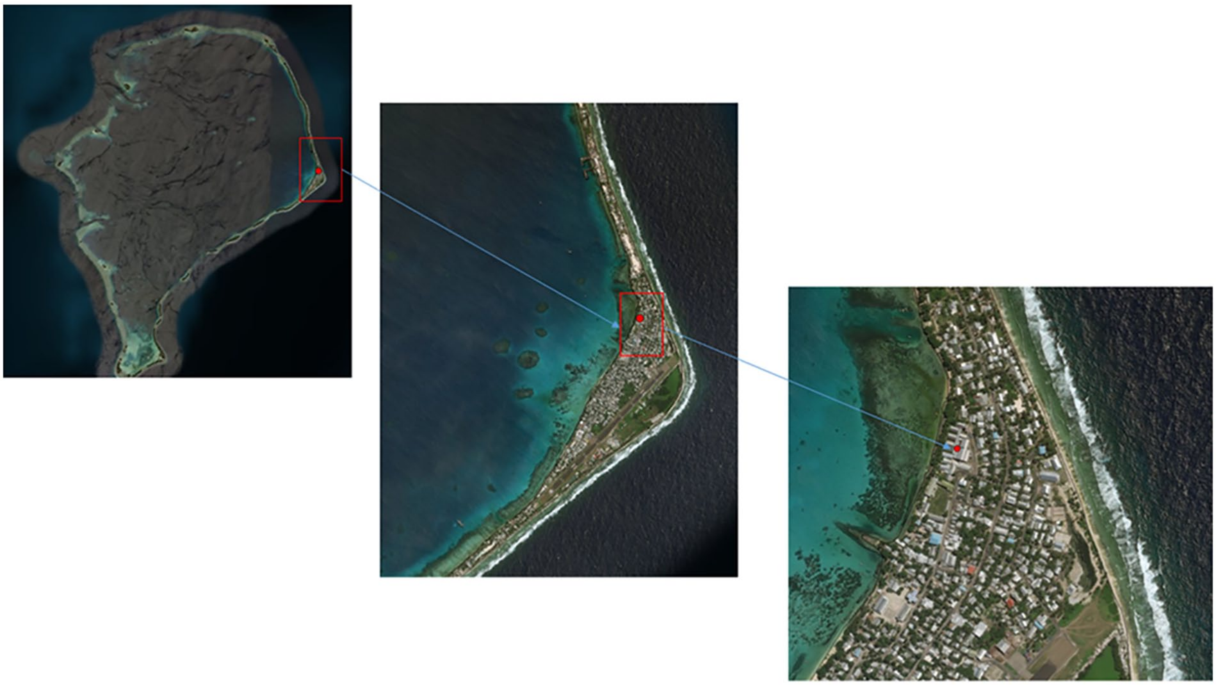

Figure 2. The red dot represents location of Princess Margaret Hospital within 50 m of the coastline on Funafuti, the capital of Tuvalu
Source: Google Earth.

Figure 3. The red dot represents location of Tungaru Central Hospital within 100 m of the coastline on Tarawa, the capital of Kiribati.
Source: Google Earth.

The interactions between climate change and non-communicable diseases (NCDs) is another area of concern as climate change could potentially exacerbate the existing and rapidly increasing burden of NCDs in PICs.[10] High rates of obesity and related NCDs, such as hypertension and Type 2 diabetes are common in PICs.[28] Extreme weather events could not only lead to crop damage but climate change could also cause deteriorations in the conditions for domestic agriculture. In such instances, populations in the PICs could become overly reliant on canned and highly processed food items such as white rice and canned fish. Hotter and wetter conditions could also affect the willingness or ability to exercise and undertake outdoor work.[10]

Medical infrastructure that is disaster-proof and climate resilient is essential for health sector adaptation to climate change in the Pacific.[10] This study has shown that a large

Figure 4. The red dot represents location of National Referral Hospital within 50 m of the coastline in Honiara, Solomon Islands.
Source: Google Earth.

proportion (62%) of critical health infrastructure in the 14 PICs studied here are located within 500 m of the coast. These include not only small and remote medical centers but also some of the larger referral hospitals. These locations make hospitals highly susceptible to sea level rise, particularly during high tides and storm surges. Tropical storms and floods pose additional threats to such critical infrastructure. The low-lying coral atoll countries such as Kiribati, Tokelau, Tuvalu, and Marshall Islands are particularly vulnerable because they have a very limited number of hospitals and these are located within close proximity of the coast. Previous studies have also identified these 4 countries as having mostly very high or high indicative susceptibility to coastal erosion induced by climate change.[9]

The fifth assessment report from the IPCC states, with high confidence, that sea level rise "poses one of the most widely recognized climate change threats to low-lying coastal areas on islands and atolls."[29] The report identified damage to health and safety infrastructure as a significant impact of tropical cyclones on small islands. Projections based on the Representative Concentration Pathway (RCP) 4.5 indicate sea level increases of 0.35 to 0.70 m by the year 2100.[29] This level of increase, on its own, does not directly pose a threat to the health care facilities identified in this analysis as being vulnerable. However, these facilities are susceptible to damage when combined with events such as storm surges, king tides, wave action, cyclonic wind, and high spring tides. For example, Princess Margaret Hospital on Fongafale Island, Funafuti Atoll, Tuvalu is highly vulnerable to such events because some parts of the central portion of Fongafale are below high spring tide level with rates of relative sea level rise at Funafuti between 1950 and 2009 being reported at 3 times higher than the global average.[30] Similarly, health care facilities located in low-lying flood prone delta areas, such as the Rewa Delta on Viti Levu, Fiji, are susceptible to flooding associated with cyclones.[31] Remotely generated swell waves combined with sea level rise can also lead to widespread inundation events causing severe damage to infrastructure as was reported in 2008 in 5 PICs (Marshall Islands, Kiribati, Papua New Guinea, and Solomon Islands).[32]

The countries in this region of the world have limited representation in global analyses of vulnerability to sea level rise and associated threats, yet they have been identified as among the most vulnerable societies in the world to the health impacts of a changing climate.[12,13] The main reason for this is limited availability of data of sufficient spatial resolution. For example, including elevation data would have enhanced the findings from this study. This is a limitation of this study. However, elevation data at sufficient vertical accuracy are not available for most of the PICs in this region due to the cost associated with the collection of such data. Furthermore, identifying the exact locations of all medical facilities was highly dependent on the information available on the Ministry of Health website. This website was well maintained and kept updated in the case of some countries but not others. As a result, the analysis had to leave out some medical facilities because they could not be reliably located. As such, this study is an attempt at providing a baseline analysis of the threats posed by sea-level rise to existing critical medical infrastructure in 14 PICs. This assessment can serve as an important first step in adaptation efforts.

One of the initial steps that could be taken is to ensure that the MoH in PICs have an up to date record of all active medical facilities located within the country including accurate locational data as well as the services provided by each facility. Such data would aid future analyses of the vulnerability of medical infrastructure to climate change and sea level rise. It would also assist in emergency preparedness and management as facilities that are at immediate risk, particularly during cyclones, king tides, and storm surges can be rapidly identified and evacuated. It would also identify current facilities that will need to be made resilient so that they remain safe and functional during episodes of extreme weather. One of the long-term goals would be to ensure that any new medical infrastructure are built with the current and future climate in mind. This would include paying close attention to climate-resilient building codes in the design of new medical facilities. Building new medical facilities and relocation of existing infrastructure requires funding which may not be readily available in PICs resulting in reliance on external funding from more developed and wealthy countries for adaptation work associated with health impacts of climate change.

Authors Contribution

S.T. was responsible for data collection, analysis and writing the paper.

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