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Review

Health risks of climate change in the 21 Pacific Island states and noted gaps in scientific evidence: A scoping review

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ABSTRACT

The Pacific Islands, a group of Small Island Developing States (SIDS), are thought to be particularly vulnerable to the consequences of climate change, highlighting the critical need for holistically assessing risks, especially those relevant to the health and wellbeing of local communities. This scoping review assesses the state of peer-reviewed literature on the health risks associated with climate change in the 21 Pacific Island states, analyzing quantitative and qualitative studies focusing explicitly on health outcomes, as well as studies focusing on health determinants or potential mediators along the climate-health pathway. The evidence in the Pacific is limited and largely geographically centered on a select few states, but highlights that climate change indicators are associated with a wide range of health outcomes, including but not limited to diarrhea, leptospirosis, typhoid fever, and mental distress. With respect to mediators, the review also reveals that infrastructural systems and policies are not sufficient to protect communities from potential health consequences in the states studied. By matching the review findings to the recommendations of the WHO Framework for Building Climate Resilient Health Systems, the paper highlights critical gaps in evidence regarding components of the framework such as climate-resilient technology, infrastructure, and climate-resilient financing. Although limited, the evidence reveals priority areas for climate adaptation. Further research that includes a focus on quantitative assessments of climate-related interventions will be critical to building resilience in one of the most at-risk regions of the world.

Introduction

Small island developing states (SIDS), including the Pacific Islands, are particularly vulnerable to the impacts of climate change, as illustrated by the recently released Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) Working Group II Report [1]. They face a wide range of acute to long-term risks, whether they be direct injuries and deaths due to intensified and more frequent extreme weather events or aggravated risks of communicable disease and non-communicable disease such as mental distress and disorders [1]. Climate change also challenges health systems by affecting access to adequate healthcare facilities during floods and storms. In addition, sea-level rise increases the risk of higher tides, which can devastate low-lying coastal areas and potentially lead to widespread population displacement [2–5].

In order to mitigate the growing impact of climate change on SIDs, the World Health Organization (WHO) declared the SIDS Initiative, an effort in collaboration with the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat and the Fijian Presidency of the 23rd Conference of Parties (COP23) (2017). The goal of the SIDS Initiative is to provide national authorities in these states with political, technical and financial support and the evidence to *1) better understand and address the effects of climate change on health, including those mediated via climate change impacts on the main determinants of health* (e.g., food, air, water and sanitation, vectors); *2) improve the climate-resilience and environmental sustainability of health services;* and *3) promote the implementation of climate change mitigation actions* in the most polluting sectors (e.g., transport, energy, food and agriculture) that will maximize health co-benefits, both within and outside these states.

In response to the initiative, the Pacific Islands developed the "Pacific Island Action Plan on Climate Change and Health" as part of the third Global Conference on Climate Change and Health, held in Nadi, Fiji, on 15-16 March 2018. This Action Plan determined the

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short-term (by 2021) and long-term (2023) action items and indicators of the four components of the SIDS Initiative.

For technical guidance, the WHO published the operational framework for building climate-resilient health systems [6]. This publication was designed to guide states on how the health sector and its operational basis in health systems systematically and effectively can address the challenges that climate change presents. This guide introduces ten key components that provide a comprehensive approach to integrating climate resilience into existing health systems. Yet, to build resilience in particularly at-risk countries or regions such as those in the Pacific, it is critical to first understand the body of knowledge on the links between climate change and health specific to these contexts.

This scoping review assesses the current extent of scientific evidence in the 21 Pacific Island member states of the WHO Western Pacific Region (WPR) that supports the goals of the SIDS Initiative. This evidence will, in turn, form the scientific foundation for the Pacific Island Action Plan (2019-2023) and long-term strategies needed to increase resilience in the region.

Methods

The Preferred Reporting Items for Systematic reviews and Meta-analyses (PRISMA) statement [7] was employed as a guide for this scoping analysis.

The inclusion criteria were 1) peer-reviewed journal articles; 2) reported climate change issues in the 21 Pacific Island states; and 3) addressed either health impacts or health determinants, including mediators and interventions. Searches were conducted in English using the PubMed database during November 2019, and non-peer-reviewed technical reports were not included. In addition, articles published before 1980 were not retained for the analysis.

Both Medical Subject Headings (MeSH) terms and free-text terms were used. The search strategy included the list of Pacific Island states ("American Samoa" or "Cook Islands" or Fiji or "French Polynesia" or Guam or Kiribati or "Marshall Islands" or "Federated States of Micronesia" or Narau or "New Caledonia" or Niue or "Commonwealth of Northern Mariana Islands" or Palau or "Pitcairn Islands" or Samoa or "Solomon Islands" or Tokelau or Tonga or Vanuatu or "Wallis and Futuna") and one climate change indicator at a time. These indicators were "*climate change*", "*drought*", "*flood**", "*sea level rise*", "*ocean acid**", "*cyclone*", "*deforestation*", "*extreme weather*", "*extreme heat*", "*ocean salinity*", "*sea temperature*", and "*heatwave*". Each climate change indicator was combined with the list of states and searched separately. Results were compiled, and duplicates were removed.

The entire research team performed the initial searches, and two reviewers (AM and IP) independently reviewed the titles and abstracts of all articles for any indication of a human health link. The articles the two reviewers agreed to accept and the ones on which they disagreed were sent to two other reviewers (HK and AR). The second set of reviewers independently assessed the titles and abstracts of these articles, discussing any disagreements that arose over article inclusion until a consensus was reached on the final list of articles to be used for full-text review. After the final agreement, data were extracted using the predefined Excel data extraction form. The data were analyzed for four domains: 1) quantitative evidence, 2) qualitative evidence, 3) evidence on potential mediators and interventions, and 4) congruence with the WHO operational framework for climate-resilient health systems. Through the quantitative and qualitative evidence synthesis, we extracted climate change indicators, health outcomes and the reported evidence of the link between climate change and health outcomes. In addition, the data synthesis involved extracting evidence for reported mediators and interventions. Publications that did not directly assess health outcomes (e.g., articles that focus on reported interventions, social determinants, and other factors that lie on the causal pathway between climate

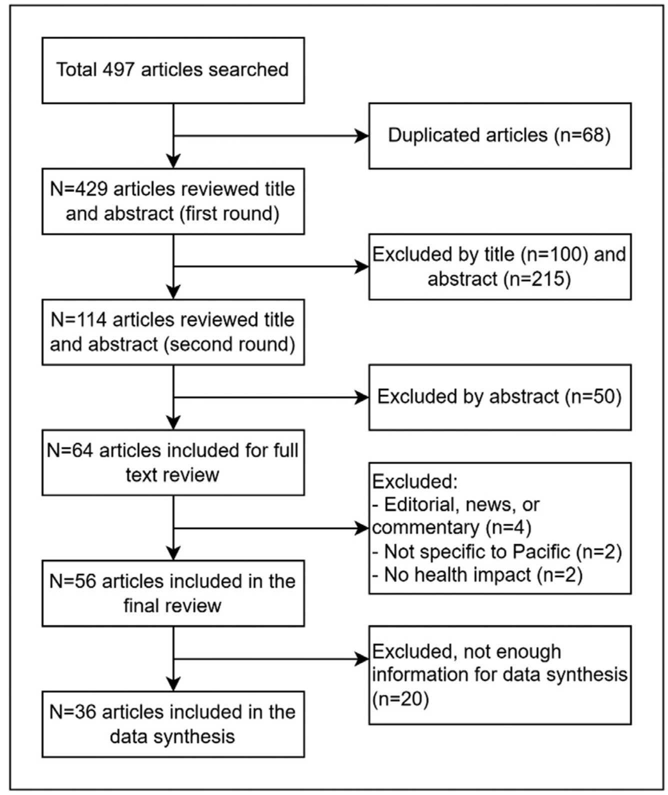

Fig. 1. Literature selection flow chart

hazards and human health) were also included if there were potential links made between mediators and health. Lastly, relevant articles were assigned to each of the ten components of the WHO operational framework for climate-resilient health systems and research gaps for each component were assessed.

From the 497 articles retrieved at the initial screening, 56 were deemed relevant to this investigation, and finally, 36 articles were included for the data synthesis. (see Fig. 1).

Role of the funding source

This study was funded by WHO, who had no involvement in study design, data collection, analysis, or interpretation or any aspect pertinent to the study.

Results

A total of 36 articles were selected for analysis and classified by type of assessment, namely 1) *Quantitative assessment*, 2) *Qualitative assessment*, and 3) *Assessment of potential mediators or moderators* (Table 1).

Among the 36 articles, 15 reported quantitative assessment results demonstrating statistical analysis and the estimated direction and effect size of associations between climate change indicators and health outcomes that provided robust scientific evidence for the impacts of climate change on health. Another nine articles provided qualitative assessment results, which provided less generalizable scientific evidence of climate change impacts on health. These articles included interviews, focus group discussions, or stakeholder workshops for health impact assessment (HIA). The remaining 12 articles were categorized as assessments of potential mediators or moderators. These articles did not study human health impacts directly but focused on the impacts of climate change on potential mediators or

Table 1
Articles included in the analysis and classified into three groups. Blank cells indicate no article found.

State	Quantitative assessment *(Stronger evidence)*	Qualitative assessment *(Weaker evidence)*	Potential mediators /moderators *(Potential risk to health)*
American Samoa (ASM)*			
Cook Islands (COK)			
Fiji (FJI)	Scobie, 2014 [8] Lau, 2016 [10] Jenkins, 2016 [12] Alwis, 2018 [14] Togami, 2018 [15]		Morrow, 2013 [9] McPherson, 2018 [11] Mosley, 2004 [13]
French Polynesia (PYF)		Chinain, 2019 [16]	Wynsberge, 2017 [17]
Guam (GUM)			
Kiribati (KIR)		McIver, 2014 [18]	
Marshall Islands (MHL)		Ahlgren, 2019 [19]	
Federated States of Micronesia (FSM)	McIver, 2015 [20]	McIver, 2015 [20]	
Nauru (NRU)			
New Caledonia (NCL)	Perez, 2011 [21] Teurlai, 2015 [22]		
Niue (NIU)			
Northern Mariana Islands (MNP)			Keim, 2010 [23]
Palau (PLW)			
Pitcairn Islands (PCN)			
Samoa (WSM)			
Solomon Islands (SLB)	Jones, 2016 [24] Smith, 2017 [27] Natuzzi, 2016 [30]	Asugeni, 2015 [25] Spickett, 2014 [28]	Shortus, 2016 [26] Fleming, 2019 [29]
Tokelau (TKL)			
Tonga (TON)			Finau, 1986 [31]
Tuvalu (TUV)	Emont, 2017 [32]	Gibson, 2019 [33]	
Vanuatu (VUT)	Pomer, 2018 [34] Pomer, 2019 [36]	Spickett, 2013 [35]	
Wallis and Futuna (WLF)			
Region	Singh, 2001 [37]	McIver, 2016 [38]	Bailey, 2014 [39] Pendleton, 2016 [40] Rumsey, 2014 [41] McIver, 2017 [42]
# of articles	***15***	***9***	***12***

*The International Organization for Standardization (ISO) three-letter country code

risk factors for human health, including aquaculture (the primary source of human nutrition in the region) and water quality. Notably, the literature's geographical scope was skewed, with Fiji and the Solomon Islands being the most studied (eight and seven articles, respectively), followed by Vanuatu (three articles). Two articles each were published regarding French Polynesia, Federated States of Micronesia, New Caledonia, and Tuvalu. Only one article focused on Kiribati, Marshall Islands, Northern Mariana Islands and Tonga, respectively. No articles meeting the inclusion criteria were identified for the rest of the states (namely American Samoa, Cook Islands, Guam, Nauru, Niue, Palau, Pitcairn Islands, Samoa, Tokelau, and Wallis and Futuna). Six articles were published regarding the region in general, without a specific national focus.

Quantitative assessments on climate-health linkages

Climate change indicators

Of the 15 quantitative assessments reviewed, as indicated in Fig. 2, eight articles assessed a one-time extreme weather event, including cyclone [8,34,36], flood [10,15,24,30], and drought [32]. The other seven articles assessed the impact of chronic climate change indicators [12,14,20–22,27,37], including patterns or trends of rainfall, temperature, or sea-level rise, but limited the observed period of the climate variation to 1-3 years.

Health outcomes

Most of the 15 articles assessed the association of potential or actual communicable diseases with climate change indicators (Fig. 3). Diarrhea (n=5) [20,24,30,32,37] was the most studied health outcome, followed by leptospirosis (n=4) [10,15,20,21], dengue (n=3) [20,22,30], typhoid fever (n=3) [8,12,14], and malaria (n=2) [27,30].

Quantitative evidence on the link between climate change and health

One common statistical method that can be used to assess climate change and health impacts is time-series regression modelling that

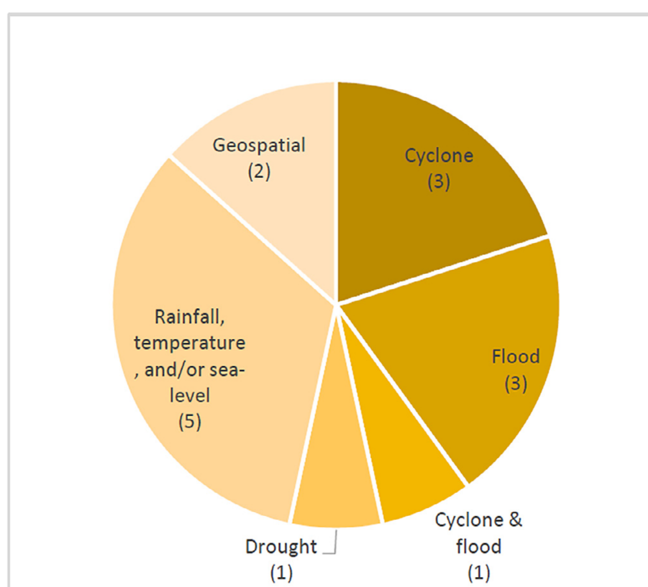

Fig. 2. Climate change indicators assessed among 15 articles reported quantitative association between climate change and health

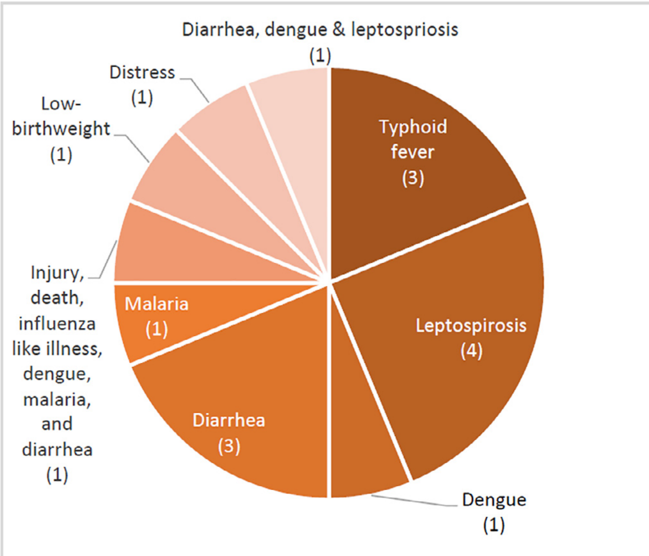

Fig. 3. Health outcomes assessed among 15 articles reported quantitative association between climate change and health

evaluates the association between longitudinal trends of climate change indicators and health outcomes while controlling for confounding and effect modification in addition to consideration of the potential lag time between the climate change indicators and health outcomes. Among the 15 articles that performed quantitative assessments, none conducted a longitudinal assessment (Table 2). Nevertheless, these articles provided useful information to understand the risk of selected health outcomes in a short-term period.

Studies [10,15,20,21] found that leptospirosis was strongly associated directly with cyclones and flooding or with geospatial characteristics such as elevation, slope, distance to major rivers, creeks, and poorly drained soils that increase the risk of flooding. Typhoid was also associated with flooding and rainfall; however, Scobie et al. [8] and Alwis et al. [14] also reported a strong protective effect of typhoid vaccination. Regarding diarrhea, Singh et al. [37] and McIver et al. [20] reported a positive association with increased temperature. Specifically, McIver et al. found a threshold effect at 33-34°C that increases the risk of diarrhea after a one-month lag period.

One article [32] assessing the effect of drought (as measured by amount in water tanks) on diarrhea found that the risk of diarrhea more than doubled in households with water tanks that were less than 20% full, suggesting that poor hygiene due to a shortage of water may increase diarrhea risk.

Qualitative assessments of climate-health linkages

Climate change indicators

Of the nine articles providing qualitative evidence of climate-health linkages (Table 3), five articles assessed multiple climate change indicators, including rainfall, cyclone, sea-level and ocean acidification [20,28,35,38]. Four articles assessed eutrophication in coral reef [16], rainfall [18], local food shortage [19], and sea-level rise [25] (Fig. 4).

Health outcomes

Instead of identifying a single health outcome, five [18,20,28,35,38] out of nine articles assessed multiple climate-sensitive diseases. These five articles reported results from the focus groups and stakeholder workshops to determine the level of risk associated with each of the selected potential climate-sensitive diseases (Fig. 5).

Level of qualitative evidence on the link between climate change and health

One article [16] addressed the risk of human health from ciguatera poisoning in French Polynesia, and another article reported the risk of malnutrition from a shortage of local food and increased dependency on imported foods [19] under climate change conditions. Another study [25] evaluated perceived mental stress associated with sea-level rise among 57 residents of Solomon Islands and found high levels of perceived stress. The objective of another study [33] conducted in Tuvalu was to understand and ascertain idioms of mental stress perception and expression in order to assess climate change impact more accurately. This study found that the most common idioms of distress were worry, tiredness, disrupted sleep, a distracted, preoccupied or busy mind, and high blood pressure. While this study did not directly assess the link between mental health and climate change, it described expressions of distress among Tuvaluans that could help measure future mental health impacts of climate change.

Five articles employed the Health Impact Assessment (HIA) framework to understand and assign the level of risk of multiple potentially climate-sensitive diseases. HIA is a structured method for qualitatively assessing and improving health consequences of hazards of interest, which employs a multidisciplinary process combining a range of qualitative and quantitative evidence in a decision-making framework [43]. This method is useful when quantitative data are limited but local stakeholders have insight into the problems.

Assessments regarding potential mediators and interventions in climate and health

A total of 12 articles were identified as providing information on potential mediators or moderators in the relationship between climate change and human health (Table 4). While these studies did not focus on health outcomes explicitly, the main outcomes of interest are potentially on the causal pathway to human health or have modifying effects on the relationship between climate change and health.

Potential mediators

Various potential mediators were assessed, including lowered water quality, decreased giant clam health, loss of local crops (which is relevant to nutrition), drinking water salination and aquifer depletion, overcrowding of displaced people (which serve as hotspots for vector-borne diseases), low resilience of current sanitation facilities, environmental damage from a cyclone, risk of coral reef ecosystems and human dependency on the coral reefs, and weak health sector capacity in disaster response, recovery and post-disaster long-term health monitoring. All of these factors are potentially harmful to human health, and thus, even though these studies did not address human health outcomes in their assessment, the findings may be useful in planning intervention strategies.

Evidence of climate change impacts on potential mediators (determinants of health)

Two studies assessed the direct impact of climate change on the potential mediators. For example, Fleming et al. [29] assessed the vulnerability of current sanitation facilities in the Solomon Islands and identified the low resilience of the facilities to extreme weather events. Shortus et al. [26] reported an increased risk of vector-borne diseases at the post-disaster emergency centers due to the crowding of displaced people.

Table 2
Articles reporting a direct quantitative association between climate change indicators and health

State	Article	Main topic	Climate change indicator	Health outcomes	Measure	Statistical method	Main association	Limitations
FJI	Scobie, 2014 [8]	Assessing the impact of typhoid vaccination campaign after Cyclone Tomas in 2010	Cyclone event in March 2010	Typhoid fever	Crude incidence rate ratio (IRR)	Fisher's exact test	Decrease in IRR of Typhoid in high vaccination areas (IRR=0.23 (95% CI=0.13-0.41)), no significant difference in the country overall	Potential underestimation of incidence due to low testing rates, sensitivity, limits in rural areas. Potential for misclassification bias
	Lau, 2016 [10]	Human leptospirosis: risk factors, including environmental drivers for transmission	Cyclones & floods	Leptospirosis	Odds ratio	Multivariable logistic regression	Risk factors for infection included: lack of treated water; flooding risk; working outdoors; high poverty rate; and living in rural areas	Cross-sectional study post-cyclone, with no comparison to pre-cyclone infection risk
	Jenkins, 2016 [12]	Assessing the burden and spatial nature of typhoid fever	Geospatial characteristics	Typhoid fever	Incidence difference	Distance-based linear model	Typhoid fever incidence is strongly related to the total area of high erosion risk (21.4% of variation), including sub-catchment areas with high flood risk	No climate indicators were associated with typhoid incidence, likely due to lack of variation in temperature and rainfall
	Alwis, 2018 [14]	Determining environmental factors in shaping the spatial distribution of typhoid	Geospatial characteristics	Typhoid (Salmonella enterica serovar Typhi infection)	Odds ratio	Multilevel mixed-effect logistic regression	Typhoid was associated with work location, annual rainfall, rainfall during the wettest month, and rainfall during the cyclone season, and age, education, sewage disposal, typhoid fever vaccination status	Case detection may be less accurate, and spatial bias may exist due to uneven survey
	Togami, 2018 [15]	Timing and source of leptospirosis outbreak following extreme flood events	Flooding	Suspected, probable, and confirmed cases of leptospirosis	Risk ratio (RR)	Not described	Increased risk of leptospirosis (RR=3.4) associated with flooding versus non-flooding periods and with multiple animal reservoirs	The low number of probable and confirmed cases of leptospirosis - would improve with more widespread comprehensive testing
FSM	McIver, 2015 [20]	Assessing climate-sensitive infectious diseases	Temperature, sea-surface temperature abnormalities	Diarrheal diseases, dengue fever, and leptospirosis	Non-linear association with threshold effect at 33-34C	Spline regression	Threshold effect at 33-34°C to increase diarrhea with one-month lag period	Lack of diarrhea cases; Substantial gaps in the data for all three disease categories because of lapses in health information collection
NCL	Perez, 2011 [21]	Seasonal rodent abundance and Leptospira prevalence in New Caledonia	Seasonal weather variables, weather events	Leptospirosis hotspots among rodents	Prevalence difference	Fisher's exact test	Rodents were more numerous and more frequently carrying leptospirosis during hot, rainy periods, flooding periods.	Data only relied on two years and one season of heavy rain
	Teurlai, 2015 [22]	Socio-economic and climate factors associated with the spatial distribution of dengue fever	Temperature, rainfall	Dengue fever	Spatial distribution of dengue fever prevalence	Support Vector Machines (SVM)	Mean temperature, number of people per premise, and % of unemployed people were associated with the spatial distribution of dengue fever cases	Models do not include potential negative effects of extreme temperatures on dengue transmission
SLB	Jones, 2016 [24]	The flood-related outbreak of rotavirus in 2014	Floods in Honiara in April 2014	Rotavirus (diarrhea)	Rate ratio (RR)	Negative binomial regression	4,087 diarrhea cases in Honiara during the outbreak period. Baseline to the outbreak (RR=2.9 (95% CI=2.13-3.96))	Limited historical baseline data
	Smith, 2017 [27]	Links between climate and malaria transmission and developing an early warning system for the disease	Rainfall, sea-level, sea surface temperature anomalies	Malaria	Incidence rate ratio	Ordinary least squares regression	Variability in rainfall during October-December was the best predictor of malaria incidence in January-June of the following year	More localized data collection is needed to update the rainfall-malaria model and extend it to southern Guadalcanal
	Natuzzi, 2016 [30]	Assessing overall health impact after a flash flood	Flood	Injury, death, Influenza-like illness, dengue, malaria, and diarrhea	Odds ratio (OR)	Logistic Regression	Individuals living adjacent to the river during the flood were more likely to be injured or die (OR=23.2 (95% CI=12.0-45.0))	Likely underreporting of injuries caused by people not seeking help at local clinics because of their displacement
TUV	Emont, 2017 [32]	Diarrhea risk during La Niña-associated drought	Drought	Diarrhea	Odds ratio (OR)	Multivariable logistic regression	Households with water tank levels below 20% full (OR=2.3 (95% CI=1.2-4.6)) and decreased handwashing frequency (OR=3.0 (95% CI=1.5-6.1)) were more likely to experience diarrhea	Data collection occurred three years after the drought, increasing the potential for differential recall bias among participants. There was no collection of pre-drought data that would have helped determine if diarrhea cases increased during the drought
VUT	Pomer, 2018 [34]	Assessing cyclone impact to pregnant women and infant birthweight	Cyclone Pam in 2015 with exposure indicators	Low birthweight	Prevalence ratio	Multivariable linear regression	Distress (β=-34, *p*-value=0.01) was associated to lower birthweight, while maternal education (β=-0.29, *p*-value=0.03)) and sex of baby (β=-0.24, *p*-value=0.05) were also significantly associated with low birthweight	Limited sample size (n=70), scarcity of reliable birth records, did not collect data on moderators

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Table 2 (*Continued*)

State	Article	Main topic	Climate change indicator	Health outcomes	Measure	Statistical method	Main association	Limitations
	Pomer, 2019 [36]	Assessing cyclone impact to psychosocial distress among pregnant women	Cyclone Pam in 2015 with exposure indicators	Psychosocial distress score	Mean distress score difference	Multivariable linear regression	In 2016, after Cyclone Pam, distress level was lower among pregnant women (Exp(β)=0.85, *p*-value=0.01), compared to women who were not pregnant	No pre-cyclone measures of distress among women in the target population
Region	Singh, 2001 [37]	Relationship between climate variability and diarrhea incidence	High average annual temperature, low annual water availability, rainfall extremes, temperature extremes	Diarrheal disease	Crude prevalence ratio	Linear regression, time-series with Poisson regression	Cross-sectional: Positive association between annual average temperature and rate of diarrhea, inverse relationship between water availability and diarrhea cases. Time-series: In Fiji, extremes of rainfall were associated with increased diarrhea in infants (2% per unit increase of rainfall above the median and 8% per unit decrease of rainfall below the median; 3% increase of diarrhea per degree increase in temperature with one-month lag	Aggregated case data and no information on the causes, poor data accuracy on water availability

Evidence of the efficacy of policy interventions relevant to climate-health linkages

Four articles studied governmental policies and strategies. One study [9] conducted a policy analysis to assess the health impact of the current Fiji National Climate Change Policy. This study found that the policy did not adequately account for climate change impacts on human health. Such findings should be used to improve future policies in the domain of climate change and health. Another study introduced the One Health approach included in the development of the National Action Plan on leptospirosis in Fiji [11]. The approach was found to be an effective method in securing intersectoral collaboration. Shortus et al. [26] also assessed the effectiveness of the National Vector Borne Disease Control Programme in the Solomon Islands and found that rapid intervention actions can effectively prevent vector-borne diseases. McIver et al. [42] introduced a modified 'Healthy Islands' framework by identifying key actors and processes within the context of climate change and health. All four articles discuss governmental policy development and action plans as intervention methods that can mediate the impact of climate change on health.

Gaps in building climate-resilient health systems

The WHO Operational Framework for Building Climate Resilient Health Systems [6] released in 2015 provides important guidance on building climate-resilient health systems. As reported in the operational framework, Fig. 6 describes six building blocks of health systems and ten key components needed to build climate resilience.

Key findings of the reviewed articles were synthesized into the ten components of the operational framework to understand the current status and gaps in implementing the framework (Table 5).

Most of articles were grouped into three components, "Vulnerability, capacity & adaptation assessment" (n=12), "Health & climate research" (n=10), and "Management of environmental determinants of health" (n=10). No studies were relevant to the two components, “Climate resilient & sustainable technologies & infrastructure” and “Climate & health financing”. Among the ten components, “Climate resilient & sustainable technologies & infrastructure” is a key component that provides specific guidance to intervene in the climate-health pathway. The absence of published research related to this component is a critical gap in planning adaptation strategies. For example, half of the population in rural Kiribati has no access to improved drinking water, and the state has been suffering from a drinking water shortage [44]. Climate-resilient technologies should play a critical role in situations where a basic resource is limited, as in the case of Kiribati's water crisis. Only one or two articles were relevant to each of the remaining five components. To build truly climate-resilient health systems in this region, filling these knowledge gaps is an urgent priority.

Discussion

This study aimed to develop a scientific baseline of health impacts from risks of climate change in the 21 Pacific Island states by reviewing and synthesizing the existing evidence on the reported health consequences of various climate hazards.

This scoping review reveals that, although some evidence of links between climatic factors and health outcomes in the Pacific exists, the body of knowledge remains limited and geographically skewed, illustrated by the few quantitative and qualitative studies of direct health outcomes and potential mediators that have been published thus far. Still, these studies provide early evidence of a wide range of climate-health risks faced by Pacific Island states, suggesting the urgent need for further research to build the evidence base and take appropriate actions to strengthen resilience.

The quantitative studies reviewed in this paper examined climate indicators that ranged from acute extreme weather events to more

Table 3
Articles reporting a qualitative association between climate change indicators and health

State	Article	Main topic	Climate change indicator	Health outcomes	Qualitative evidence of association	Assessing method	Limitations
PYF	Chinain, 2019 [16]	Review of ciguatera range and transmission to humans	Increased eutrophication in coral reef environments	Ciguatera poisoning	Increased range of ciguatera as evidenced by spread of ciguatera cases to French Polynesia in 2008.	Literature review with descriptive analysis of ciguatera poisoning cases	Descriptive only, no link to climate change on disease vector spread
KIR	McIver, 2014 [18]	Climate change vulnerability assessment and health adaptation planning	Rainfall	Diarrhea, vector-borne disease, zoonosis, malnutrition, non-communicable diseases (NCD), mental health, respiratory disease, skin disease, poverty and socio-economic disadvantage, traumatic injuries and deaths, ciguatera	The health impact assessment framework determined three risk groups (high, medium, and low) of health outcomes related to climate change	Health Impact Assessment framework with stakeholder's discussion and agreement	Lack of reported cases; climate-sensitive diseases were determined without quantitative data-based evidence
MHL	Ahlgren, 2019 [19]	Health implications of foreign food aid to the Marshall Islands under climate change	Shortage of locally sourced food from various climate change related conditions	Diseases from inadequate nutrition due to the dependency on imported foods	Climate change reduces local food production and leads to imported food that contributes to adverse health impact	Literature review and commentary	No original data
FSM	McIver, 2015 [20]	Assessing climate-sensitive diseases	Temperature, rainfall, sea-surface temperature abnormalities	Diarrhea, vector-borne diseases, zoonosis, malnutrition, NCD, mental health, respiratory, skin, poverty and socio-economic disadvantage, traumatic injuries and deaths, ciguatera	The health impact assessment framework determined three risk groups (high, medium, and low) of health outcomes related to climate change	Health Impact Assessment framework with stakeholder's discussion and agreement	Lack of reported cases; climate-sensitive diseases were determined without a quantitative assessment
SLB	Asugeni, 2015 [25]	Assessing perceived mental stress of people in low-lying coastal areas	Sea-level rise	Mental health	Most of people reported that worry over sea-level rise affected their thinking and behavior,,majority of people noted negative effects on their communities	Questionnaire survey to 57 people across six remote villages	A small number of participants in only six villages, some villages refused to participate
	Spickett, 2014 [28]	Identifying risks to human health attributed to climate change, evaluation and prioritization of risks for adaptation strategies	Increased temperatures, altered rainfall, intense cyclones, sea-level rise, ocean acidification	Vector borne diseases, respiratory disease, water borne disease, food security, food borne disease, NCDs, trauma, heat exposure, mental health, skin and eye conditions, sexually transmitted infections	Determining health risks (extreme, high, medium, low), associated climate change adaptation and response capacity	Health Impact Assessment framework with stakeholder's discussion and agreement	Climate-sensitive diseases were determined without a quantitative assessment
TUV	Gibson, 2019 [33]	Finding local and culturally specific determinants of distress in relation to climate change	Sea-level rise, coral bleaching, ocean acidification, extreme rainfall	Mental health impacts	Identified idioms of distress, determinants and response to distress improved understanding of mental health impact from climate change in Tuvalu	Semi-structured key informants' interview to 39 residents on Funafuti atoll	The sample was restricted to residents of Funafuti, which may be different from outer islands and did not assess link to climate change
VUT	Spickett, 2013 [35]	Health impacts of climate change, assessing risks and propose responses	Increased temperatures, altered rainfall, intense cyclones, sea-level rise, ocean acidification	Vector borne diseases, respiratory disease, water borne disease, food security, food borne disease, NCDs, trauma, heat exposure, mental health, skin and eye conditions	Determining health risks (extreme, high, medium, low), associated climate change adaptation and response capacity	Health Impact Assessment framework with stakeholder's discussion and agreement	Climate-sensitive diseases were determined without quantitative assessment

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Table 3 (*Continued*)

State	Article	Main topic	Climate change indicator	Health outcomes	Qualitative evidence of association	Assessing method	Limitations
Region	McIver, 2016 [38]	Health impacts of climate change in Pacific Island Countries: vulnerabilities and adaption priorities	Temperature, rainfall patterns, sea-level rise, ocean salinity and acidity, extreme weather events	Vector-borne and zoonotic diseases, water insecurity and water-borne disease, malnutrition, increased non-communicable disease, traumatic injury and death, mental health disorders, disruption of health services	Direct effects include the traumatic injuries and deaths that occur during hydro-meteorological disasters; Indirect effects include increased pathogen loads in food and water and changes in geographic ranges of disease vectors such as mosquitoes. Adaptations include improving water, sanitation, and hygiene systems, and vector control.	WHO outlined vulnerability assessment and adaption planning using qualitative and quantitative processes	Shortage of data in many PICs

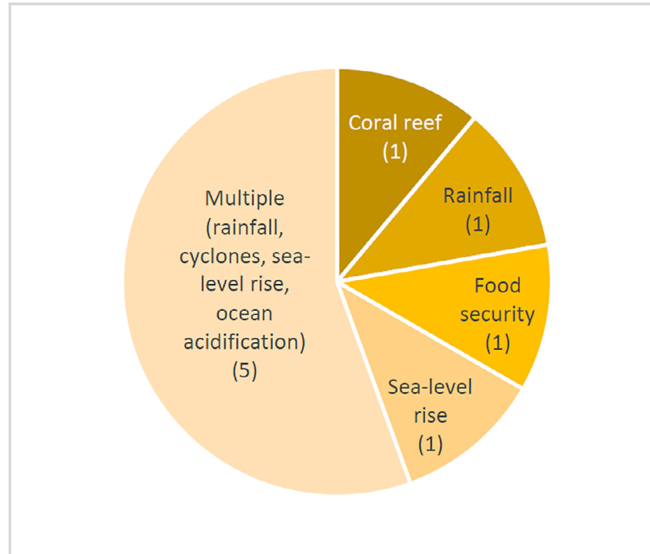

Fig. 4. Climate change indicators assessed among 9 articles reported qualitative association between climate change and health

chronic changes in meteorological variables over time. For example, the strong association found between leptospirosis and several climate indicators, including cyclone and flood frequencies, imply that disaster risk reduction initiatives must be further strengthened to prevent or mitigate not only the direct impacts (e.g. loss of life, injury, etc.), but also the indirect health impacts of such events. Since cyclones and flooding are projected to become more frequent and more intense globally [45], building resilience against these exacerbating risks in these communities will become even more critical going forward.

Moreover, quantitative studies showing threshold effects of risk factors, such as the study [20] that identified a threshold effect of temperature on the risk of diarrheal disease, provide vital information for strengthening policies and establishing early warning systems. Further research is warranted to validate the results of this study in other contexts in the region and to identify potential threshold effects for other health risks.

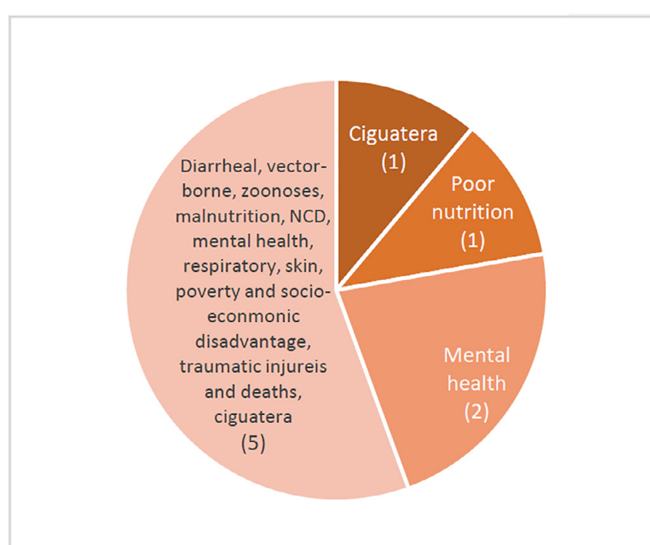

Fig. 5. Health outcomes assessed among 9 articles reported qualitative association between climate change and health

Table 4
Articles reporting potential mediators and interventions without linking to human health impact

State	Article	Main topic	Potential mediators	Policy implementation	Main findings
FJI	Mosley, 2004 [13]	Cyclone effects on drinking water quality	Water quality – residual chlorine, total fecal coliforms, and turbidity		Increased turbidity and total coliform bacteria in water samples post- versus pre-cyclone
	Morrow, 2013 [9]	Policy analysis of how the Fiji National Climate Change Policy accounts for specified health outcomes		Lack of National Climate Change Policy addressing health impact	Found the health impacts of climate change are not adequately accounted for in major relevant policies
	McPherson, 2018 [11]	Reporting procedures and findings on the national action plan for leptospirosis development		One Health multisectoral approach to strengthening governance	In the creation of a National Action Plan on leptospirosis, “One Health” approach was found to be an effective approach to securing intersectoral collaboration
PYF	Wynsberge, 2017 [17]	Assessing the impact of climate variation on giant clam health	Potential decreased giant clam health, with implications for local ecology and economy		Although the study did not link to climate change directly, the environmental conditions affecting clam health (water temperature, wave heights) were relevant to climate change
MNP	Keim, 2010 [23]	Impact of sea-level rise in two coral atoll populations	Crop loss and drinking water salination in low-lying areas from acute sea level rise		Island communities lost crop productivity and experienced drinking water salination after acute sea level rise
SLB	Shortus, 2016 [26]	Describing vector-borne disease risk assessment conducted in affected areas and interventions to reduce exposure	Crowding of displaced persons in post-disaster emergency centers as potential hot-spots of vector-borne diseases	National Vector Borne Disease Control Programme	Rapid and appropriate precautionary vector-control measures applied in a post-natural disaster setting can prevent and mitigate vector borne disease incidences
	Fleming, 2019 [29]	Association between extreme weather events and sanitation	Current sanitation facilities’ low resilience to extreme weather events		The majority of the study population had low sanitation resilience. Statistically significant difference in resilience between urban and rural areas
TON	Finau, 1986 [31]	Health and nutritional status of preschool children post-cyclone	Environmental damage after hurricane Isaac in 1982		Detailed description of management status on housing, water supply, refuse disposal, retail shops, and disease vectors
Region	Bailey, 2014 [39]	Aquifer recovery rates after marine overwash events	Salination of drinking water, aquifer depletion		On average, 20% aquifer recovery requires eight months, 80% aquifer recovery requires 20 months
	Pendleton, 2016 [40]	Mapping and ranking where coral reefs are most at risk and the human processes that depend on those coral reefs	Human dependence on coral reef ecosystems and the risk from environmental change		Western Mexico, Micronesia, Indonesia and parts of Australia have high human dependence and will likely face severe combined threats. As a region, Southeast Asia is particularly at risk.
	Rumsey, 2014 [41]	Examine the capacity of the health sector to adapt to changing disaster response (Fiji, Cook Islands, Vanuatu, Samoa)	Needs in health sector capacity building for disaster response		Elements that support the adaptive capacity of the health sector included inclusive involvement in disaster coordination, policies in place for health workforce coordination, belief in their abilities; and strong donor support. Factors constraining adaptive capacity included weak coordination of international health personnel, lack of policies to address health worker welfare, limited human resources and material resources, shortages of personnel to deal with psychosocial needs, inadequate skills in field triage and counselling, and limited capacity for training
	McIver, 2017 [44]	Using Healthy Islands Framework for health vulnerability assessment under climate change (FSM, Marshall Islands, Palau)		Implementation of Healthy Islands Framework for climate change adaptation	The study reviews the actors, processes and contexts of the climate change and health vulnerability assessment and adaptation planning project. Modified “Healthy Islands” framework for climate change and health adaptation in the Pacific

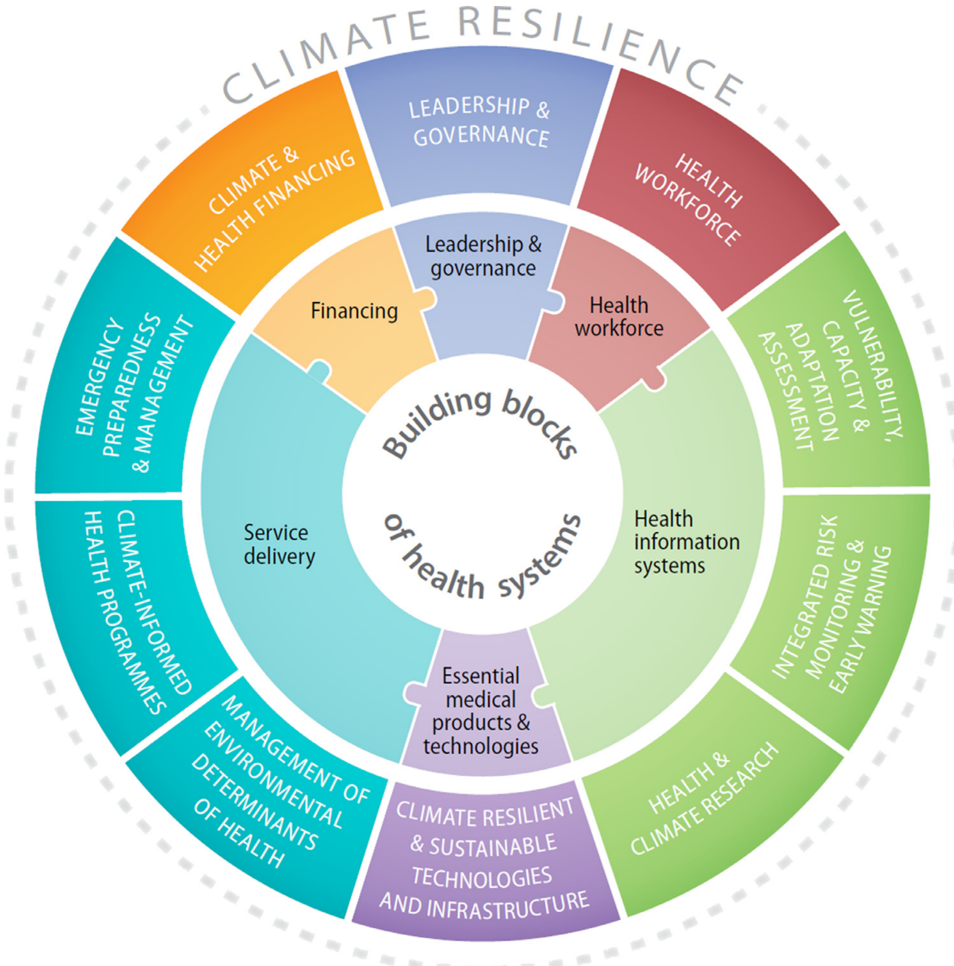

Fig. 6. Ten components comprising the WHO Operational Framework for Building Climate Resilient Health Systems, and the main connections to the building blocks of health systems[6]

While there were fewer qualitative studies than quantitative assessments, one unique feature of over half of these studies was the use of the HIA framework to identify multiple climate-sensitive diseases of concern. The HIA is a tool used in national policy appraisal, local urban planning, infrastructure projects, and climate change mitigation and adaptation projects, and its benefits include improved interagency collaboration and public participation by allowing the participation of stakeholders from various sectors. On the other hand, HIAs are limited in building the evidence base with respect to health impacts, partly due to the lack of consensus regarding the methods to be applied [46]. In other words, while HIA is a useful tool for developing policies and action plans, it is based on the precautionary principle that does not require accurate evidence of specific epidemiologic causation. While studies based on the HIA framework provide a useful starting point to identify health outcomes of potential concern, the recommended approach would be to follow up with a quantitative assessment to quantify the potential risks of such outcomes.

In addition to studies focusing on the direct impacts that climate-relevant indicators have on health outcomes, it is equally important to investigate mediators that occur along the climate-health causal pathway. Understanding how climate change may affect health determinants and how climate policies may impact these mediators can help identify potential upstream points of intervention. For example, given that poor sanitation has been shown to be the main risk factor of diarrhea and diarrheal deaths [47], the findings of Fleming et al. [29] that sanitation facilities in the Solomon Islands are vulnerable to extreme weather events is valuable not only in gauging present and future risk of diarrheal disease, but also identifying an important point of intervention for climate adaptation and public health.

Several limitations may be present with this study. Among the various information collection methods that exist, we employed only the PRISMA method because it is the most common method for systematic reviews and meta-analyses; as such, information not captured by this approach may have been missed. Although we followed PRISMA criteria, the quality of the selected articles was not an essential criterion for inclusion because of the limited number of articles per state. Except for Fiji and Solomon Islands, only 1-2 articles per state were included in the analysis. However, by including only peer-reviewed articles, a certain level of quality was expected. In addition, the search database was limited to PubMed due to time restrictions. More articles may be available in other databases and Google Scholar that we may have missed. This analysis did not include technical reports published by the government, international agencies, and non-profit organizations, which may have provided additional information. However, technical reports often focus on summarizing existing literature and providing descriptive reports of cases or other impacts of health hazards while our study was focused on identifying studies that examined associations using epidemiologic analyses.

This analysis only included English-language publications, and non-English-language publications were not captured by the key search using English terms. Among the 21 states included in our analysis, only two states, French Polynesia and New Caledonia, use a non-English language (French) as their official and national language. While government reports and local communications in both

Table 5
Ten components of WHO operational framework and matching with published findings in the 21 Pacific states

Component	Article	State	Link to framework component
Leadership & governance	Morrow, 2014	FJI	Does Fiji climate change policy account for the effects of climate change on human health?
	Mcpherson, 2018 [11]	FJI	Effectiveness of One Health approach of National Action Plan on leptospirosis
	McIver, 2017 [42]	Region	Testing traditional health governance in response to climate change and health adaptation
Health workforce	Rumsey, 2014 [41]	Region	Needs in health sector capacity building for disaster response
Vulnerability, capacity & adaptation assessment	Spickett, 2013 [35]	VUT	Evaluation and prioritization of health risks for adaptation strategies: Vanuatu
	Spickett, 2014 [28]	SLB	Evaluation and prioritization of health risks for adaptation strategies: Solomon Islands
	McIver, 2016 [38]	Region	Impact of climate change adaptations, including improving water, sanitation, hygiene systems, and vector control
	Lau, 2016 [10]	FJI	Factors associated with increased vulnerability to human leptospirosis
	Teurlai, 2015 [22]	NCL	Socio-economic factors associated with the distribution of dengue fever cases
	Natuzzi, 2016 [30]	SLB	Injury vulnerability of individuals living adjacent to the river during the flood event
	Emont, 2017 [32]	TUV	Household water tank level and decreased handwashing associated with diarrhea vulnerability
	Jenkins, 2016 [12]	FJI	Typhoid incidence from leptospirosis is related to areas with high flood risk and high erosion risk
	Alwis, 2018 [14]	FJI	Annual rainfall, proximity to rivers, and floodable areas were major environmental risk factors for typhoid
	Fleming, 2019 [29]	SBL	Sanitation resilience to extreme weather events
	Pendleton, 2016 [40]	Region	Human dependence on coral reef ecosystems and the risk from environmental change
Integrated risk monitoring & early warning	McIver, 2015 [20]	FSM	Health impact assessment of climate change - potential for using diarrheal disease as a climate-based early warning system
	Smith, 2017 [27]	SLB	Links between climate and malaria transmission and developing an early warning system for the disease
Health & climate research	Chinain, 2019 [16]	PYF	Climate-sensitivity of disease and risk to communities
	McIver, 2014 [18]	KIR	Health impact assessment of increased rainfall
	Asugeni, 2015 [25]	SLB	Mental health impacts of sea level rise
	Gibson, 2019 [33]	TUV	Determinants of distress in relation to climate change
	Togami, 2018 [15]	FJI	Leptospirosis outbreak following extreme flood events
	Perez, 2011 [21]	NCL	Spread of rodent-borne leptospirosis during extreme weather periods
	Jones, 2016 [24]	SLB	A flood-related outbreak of rotavirus
	Pomer, 2018 [36]	VUT	The effect of cyclone exposure during pregnancy on infant birthweight
	Pomer, 2019 [36]	VUT	Psychosocial distress among women following a natural disaster
	Singh, 2001 [37]	Region	Relationship between climate variability and diarrhea incidence
Climate resilient & sustainable technologies & infrastructure	**NONE**		
Management of environmental determinants of health	Ahlgren, 2019 [19]	MHL	Food and nutrition security
	Mosley, 2004 [13]	FJI	Cyclone effects on drinking water quality
	Wynsberge, 2017 [17]	PYF	Assessing the impact of climate variation on giant clam health
	Keim, 2010 [23]	MNP	Loss of crops and drinking water salination in low-lying areas from acute sea-level rise
	Finau, 1986 [31]	TON	Health and nutritional status of preschool children post-cyclone
	Bailey, 2014 [39]	Region	Salination of drinking water, aquifer depletion and recovery after marine overwash events
Climate-informed health programs	Scobie, 2014 [8]	FJI	Assessing the impact of a typhoid vaccination campaign after a cyclone
Emergency preparedness & management	Shortus, 2016 [26]	SLB	Crowding of displaced persons in post-disaster emergency centers as potential hotspots of vector-borne diseases
Climate & health financing	**NONE**		

countries use French, we expect that peer-reviewed publications in French on the research topic are likely to be limited, and thus, their impact on our findings may be negligible.

Our study highlighted that, despite widespread recognition that the Pacific is highly vulnerable to climate risks, only 36 peer-reviewed publications in total have been published in the 21 member states since 1980. There is therefore an urgent need to strengthen the region's capacity to conduct epidemiologic investigations to understand the causal mechanisms, intervention opportunities, and effectiveness of implemented interventions. This may involve developing curricula in universities, conducting workshops and webinars for government policymakers and technical staff and researchers, and forging research partnerships between governments and universities in and beyond the region. The WHO WPR can also play a key role in capacity-building by coordinating regional trainings that highlight the best available science and research gaps, and providing technical assistance to member states to fill those gaps.

Conclusion

This scoping review presents some evidence of how climate-related factors impact health or its determinants in a handful of Pacific Island states. Given the limited number of studies conducted, especially those that quantify risk, more scientific evidence is urgently needed to assess current and future vulnerability to climate change and the adaptive capacity of island states in the Pacific. It is recommended that the governments of the 21 states review the findings of this literature review, align plans and activities with the evidence that is available, and support efforts to fill the significant knowledge gaps. Matching the existing knowledge to the ten components of the WHO Operational Framework for Building Climate Resilient Health Systems revealed that there is little to no scientific evidence for more than half of the components in the region. Thus, further examination of potential strategies and approaches for building this evidence is warranted. A rigorous scientific investigation will help identify the most appropriate paths to achieve the goal of building climate-resilient health systems without undue delay or expense. This investigation provides a comprehensive overview of the existing research and identifies knowledge gaps regarding climate change and health risks in the Pacific Islands. The insights gleaned can guide future planning efforts to build climate resilience in one of the most at-risk regions in the world.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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