

Food for thought: Climate change risk and food (in)security in Tuvalu

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ABSTRACT

Climate change presents a considerable threat to food security of low-lying atoll nations in the Pacific including Tuvalu. It is projected to heavily impact agricultural and fishery sectors in Tuvalu, threatening food chains and the ability of Tuvaluans to produce and access safe and nutritious food that meets their dietary and cultural needs. In addition to climate change impacts, food security in Tuvalu is affected by a number of interconnected socio-economic, transboundary and ecosystem factors including access to land, traditional food-acquiring skills, food availability and affordability, cultural practices and the changing way of life. In fact, decline in traditional food-acquiring skills, the lack of interest in local food production practices, and other unfortunate socio-economic circumstances continue adversely affecting food (in)security in Tuvalu. This study assessed the risk of climate change from the perspective of food security domain considering exposure to flood hazard. The results of risk assessment suggested that revival of traditional food-acquiring skills is an important adaptation strategy. Strategies at the community and government levels are proposed to prevent adverse impacts of flooding on and prevent food security in Tuvalu.

1. Climate change risk and food security in Tuvalu

Tuvalu is made up of nine inhabited islands scattered around 900,000 km² (km²) in the Pacific with 11,000 inhabitants ([47]; [1]). These islands are less than five meters above sea level and average 1.83 m above mean sea level [2]. The low topology puts inhabitants at risk of submerging under sea level as a result of the accelerated adverse impacts of climate change [3]. Continuous ecological changes increase the likelihood of a flooding that severely affect lives, livelihoods and critical infrastructure ([39]).

Tuvalu is classified as one of the Least Developed Countries and fourth smallest independent state in the world [4], and due to the unavoidable and tangible impacts of climate change is also ranked as one of the most vulnerable countries. Climate change have affected various socio-cultural, economic, and environmental dimensions of life in Tuvalu. Funafuti, the capital of Tuvalu, has undergone substantial changes in human settlement patterns in the last decade. More than 60% of Tuvaluans in Funafuti have altered their land use and vegetation cover [5]. High population density in Funafuti (4300 persons/km²) means that there are extremely limited areas for food cultivation. Also,

the higher fuel prices and threats such as COVID-19 heavily impacted the food security in Tuvalu, in particular, the remote islands within the country [1,6].

The IPCC AR6 [7] projected that sea level rise under different Shared Socioeconomic Pathways (SSPs)¹ for Tuvalu will be in the range from 0.5 m to 1 m by 2100. Under all scenarios, the frequency, intensity, and impacts of extreme weather events such as flooding are projected to increase too. The resulting increased soil salinisation, coastal erosion, and seawater intrusion into freshwater ecosystems will lead to the higher vulnerability to food insecurity of Tuvaluans [8,9].

The connections between floods and food security are strongly inter-related as food availability can be highly threatened by flood events which impair food availability, access, utility, and stability through direct and indirect impacts on agriculture [48]. Therefore, it is important to understand the nexus of climate change risks associated with food security and flood to identify transformative adaptation options (i. e., adaptation that embodies transformation rather than incremental adaptation) to ensure food security for Tuvalu.

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¹ Shared Socioeconomic Pathways (SSPs) are scenarios of projected socioeconomic global changes up to 2100

2. Food sources and livelihood in Tuvalu

People rely on local food (from agriculture and fishery) and imported food to secure their livelihood in Tuvalu. Fisheries sector contributes up to 60% of government revenue [1]. Over the past half century, agriculture, fishing, and local (in-country) food production (per capita for domestic consumption) have declined and a dependence on nutrient-poor imported foods has increased.

Subsistence agriculture is common, and people grow food crops only to meet their needs. Majority of population are involved in growing crops (69%) and raising livestock (84%) [47]. Main cultivated crops are coconut, babai (swamp taro), taro, breadfruit, pandanus, banana, pumpkin, sweet potatoes and pawpaw; and key domesticated animals are pigs, chicken and ducks. People commonly grow banana and pawpaw trees and cultivate pumpkin, cabbage, and cucumber in small gardens in Funafuti. Pulaka is a Tuvaluan traditional stable food crop; unfortunately, 50–80% of the pulaka pits in Funafuti are abandoned due to the changing dietary preferences, declining interest in pulaka cultivation, periodic drought, and saltwater intrusion [2] and there is a little evidence of commercial pulaka growing. Soil of Tuvalu is not generally suitable for farming, and rising sea level, flooding, and drought have an adverse impact on the limited cultivation of food crops particularly on pulaka and taro [2,10]. Local food production, coconut replanting plans and developing agricultural commercial activities were identified as priorities in the National Strategy for Sustainable Development 2021–2030 [11].

Tuvaluans also rely on marine sources for nutrients, particularly for protein [2]. Anon [10] indicated that 60% of population are engaged in fishing, with reef and lagoon fishing being most common. Climate change impacts such as rising sea surface temperatures (already about 29 °C) and ocean acidification are the main reasons for coral bleaching and degradation, which – as main habitats of fish, particularly tuna – degrade marine productivity. There is a plan to develop a sustainable commercial fishery at a small scale to contribute to income generation, food security, and healthier diet [11].

The reliance on imported food has caused the economic vulnerability of people in the food sector [2,12]. It is implicated in the expansion of noncommunicable diseases like diabetes and obesity, which are common among people living in urban settings with largely non-traditional diet. It was estimated that Tuvaluans spend one-third of their income on imported goods including chicken, rice, sugar, and biscuits.

Recognising the importance of food security, the Government of Tuvalu has published the Tuvalu Agriculture Strategic Marketing Plan (TASMP) (2016–2025) to revive and improve trade of agricultural products that are produced locally through domestic activities and other agreements [13].

Several national studies (e.g., [14–16]) show that climate related stressors of food security vulnerability vary across regions and could affect various vulnerability domains. Examples of climate change stressors and their impact on the flood security are shown in Table 1.

3. Methodology

Vulnerability to food (in)security in this paper is based on the sensitivity and adaptive capacity of the community to the impact of climate change on food security [41], [22,23]. It has been categorised in four domains (i.e., built environment, natural environment, social and economic). The adverse impacts of climate change on agriculture, fisheries, livelihoods, and infrastructure threaten all four dimensions of food security: meal size, meal frequency, access to food resources, and potential of food production/ reliance on imported food [24].

We assessed risk as a function of food security vulnerability, flooding hazard and its exposure based on IPCC [22] risk assessment guidance and Tuvalu Coastal Adaptation Project (TCAP) of Green Climate Fund, and from the perspectives of the local communities and experts, as outlined in Fig. 1. The flood risk map are shown in Fig. 2.

Interviews and surveys were used to collect reliable information within four weeks in 2017 in Funafuti, Tuvalu. A total 30 Tuvaluans, voluntarily, from eight main island communities Funafuti; Nanumea (2), Nanumaga (2), Nui (3), Niutao (4), Vaitupu (5), Nukufetau (4), Funafuti (5) and Nukulaelae (5) Island communities were interviewed. In addition, 10 interviews were conducted to gather information from experts from the government departments (Climate change and Disaster Department, Environment Department, Fisheries Department, Agriculture Department, Meteorological Department, Education Department, NGOs, and Environment National Project Departments). These organisations were selected due to their multi-sectoral roles in addressing climate change issues. Harnessing local communities' and experts' knowledge, we assessed Tuvalu's physical, social, economic and infrastructural vulnerabilities and investigated a number of indicators of food security vulnerability to climate change.

The primary data collected through interviews and questionnaires from the study area (Funafuti) are supplemented and validated with secondary research from the literature review and analysis of national and international climate change and food (in)security documents and reports. We applied a qualitative method considering the results of food security vulnerability and data for flood exposure in Tuvalu. Vulnerability across all four domains (i.e., natural environment, built environment, social and economic) are ranked as high, moderate, and low based on respondents' responses. Climate change is expected to increase flooding by rising sea level and higher-magnitude tropical cyclones, that will affect cultivated land and assets. This information contributes to identifying where the flood hazard/risk is highly affecting food security elements (cultivation land and assets) and is predicted to increase under climate change. Due to a lack of consistent flooding hazard information, exposure was estimated using research on flooding risk in Tuvalu. Flood risks considered the projected sea level rising scenarios in Tuvalu involving various SSP scenarios by 2100.

The results of risk assessment were used to identify adaptations/response options, such as if the emergency actions are needed or if the current levels of action should be sustained to prevent adverse impacts of flooding on food security. Based on the understanding of climate risks, impacts, and vulnerability, strategies for transformative adaptations to protect Tuvalu's food (in)security at the community and government levels are proposed.

3.1. Flooding exposure in Tuvalu

Tuvalu, particularly Funafuti, as a low-lying atoll is increasingly affected by the ocean wave energy due to rising sea level and degrading fringing reefs in coastal areas [25]. The flooding event is called "king tide" (a layman's term used in the Pacific) in Tuvalu [26]. Based on the definition of NOAA² and local knowledge of Tuvaluans, king tide is a flooding event that normally occurs once or twice a year. The studies on 28 king tide events show that there are approximately 1.5 king tide every year in Tuvalu [26], that confirms above mentioned definition of king tide.

Ninety percent of flooding events in Funafuti atoll have occurred between January and March [5,26]. Internal lagoon, coastlines and low-lying regions are the most affected areas [16]. Flooding from king tides and waves could be 3–5 m [10]. Lin et al. [26] indicated a king tide with 3.2-m height could inundate half of Fongafale land. Flooding has washed the coastline, destroyed cultivated lands, contaminated freshwater, and decreased the productivity of agricultural crops [27].

Tuvalu is projected to experience more frequent and more destructive flooding events [25] and the loss of the entire atoll. It is classified as highly vulnerable to sea level rising [9]. Becker et al. [49] estimated the mean sea level rising in Funafuti is currently 5.1 mm/year, which is three times higher than the global average. One of the main

² The National Oceanic and Atmospheric Administration of the United States

Table 1
Climate related vulnerability in food (in)security.

| Domain | Climate related stressors | Findings | References |
|---------------------|---|---|--|
| Natural environment | Increased crop quality and quantity | There are multidimensional and complex interactions between environmental change, production of fruit and vegetable, diet and health. | [17] |
| Social | Nutrition and health outcomes | There is a dramatic reduction of the per capita supply of local food and increased cost of production. | [18] |
| | Population growth and urbanisation | Social factors are substantial contributors to food security vulnerability due to climate shocks. | [19] |
| Economic | Availability of food | In Australia, the decline in rainfall and increase in daily maximum temperatures based on simulations of 50 sites caused water-limited yield potential to decline by 27% from 1990 to 2015. | [20] |
| | Diversity of accessible food | | |
| | Health of food resources | | |
| | Connections | | |
| Economic | Food storage | This study projected that food security vulnerability due to climate change will be greater in the low- and middle-income regions of the world over the next decades. | [45] |
| | Mobility of people | | |
| | Equal access to land, water, and food resources | | |
| | Barriers to resource areas | | |
| | Crop yields | | |
| Economic | Changes in income | This research indicated that people spend more than two thirds of income on food in regions struggling with poor rainfall and droughts throughout El Salvador, Guatemala and Honduras. | Food security and emigration report of United Nations World Food Programme, [21] |
| | food availability | | |
| | socio-economic factors | | |
| Economic | Food price | This research indicated that people spend more than two thirds of income on food in regions struggling with poor rainfall and droughts throughout El Salvador, Guatemala and Honduras. | Food security and emigration report of United Nations World Food Programme, [21] |
| | | | |
| Built environment | Water pipe stresses and probability of failure (pipe materials, pipe diameters) | Drinking water distribution networks are vulnerable towards soil fertility, irrigation due to climate change. | Wols et al. [46] |
| | Soil types and soil maturity | | |
| | | | |

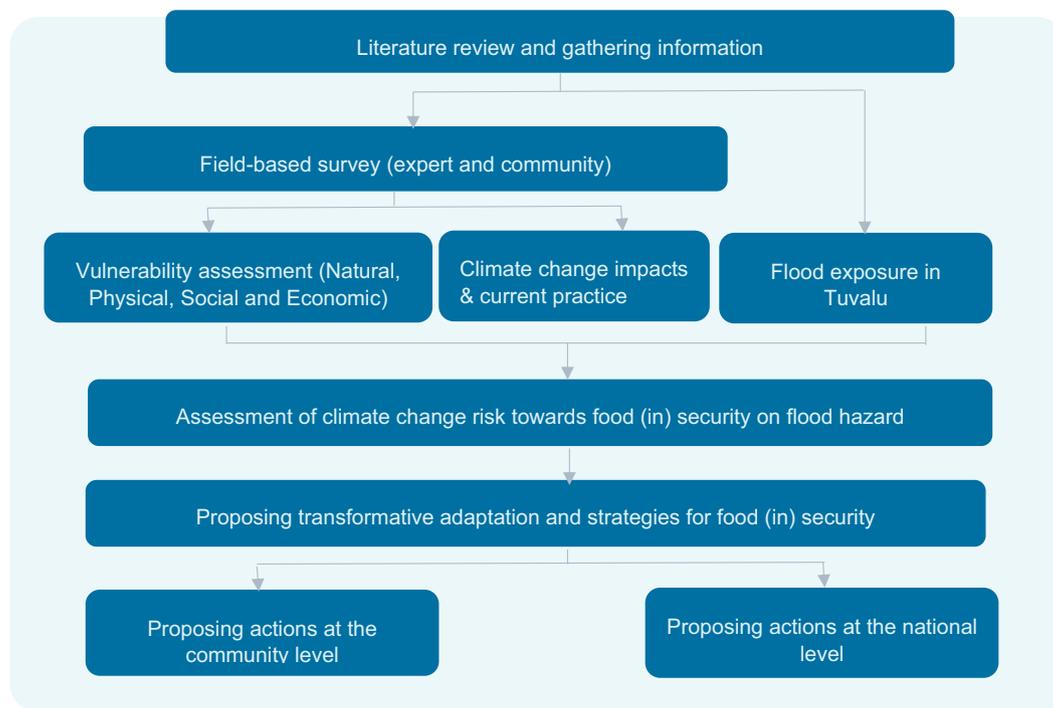


Fig. 1. Methodological framework of study.

consequences of sea level rising is the increase in reef depth that facilitates reaching the larger waves to island shorelines [26,28]. We could not consider the uncertainties related to how the coastal ecosystems in Tuvalu will naturally adapt to flood hazards under these emissions and sea level rise scenarios. However, this uncertainty should not be taken to mean that impacts of flooding and climate change on food security are entirely avoidable or unlikely to occur.

4. Tuvalu’s vulnerability to climate change risks

The projected sea level rise poses an existential threat to the country ([43]; [22]). It could severely affect lives and livelihoods of Tuvaluans. Vulnerability reduction is one of the most critical elements of climate change adaptation for Tuvalu especially where it can build upon the strong cultural identity and sense of community.



Fig. 2. Flood risk map of Tuvalu (Based on the GCF TCAP project study).

4.1. Natural environment vulnerabilities

Tuvalu is extremely vulnerable to the impacts of climate change due to its geographical or physical characteristics and location close to the cyclone belt ([2,29]; [40]). The perceptions of the study participants are also that Tuvalu's geography and natural characteristics are main contributing factors for the island's high vulnerability to the impacts of climate change. The participants rate the country's natural characteristics (low-lying isolated and small island with poor soil fertility) as the most significant reasons for natural environment vulnerability. Communities and experts pointed to various changes such as coastal erosion, flooding, and soil salinization that have occurred due to the high natural environment vulnerabilities. Also, due to low soil fertility, both fertilizers and pesticides are used by farmers to improve the productivity of agriculture; however, overuse of chemicals made the land unsuitable for agriculture. Due to this, majority of the farmers abandon their agricultural lands and relocate to new locations for producing their crops.

4.2. Social vulnerabilities

The study found that local communities are socially vulnerable to climate change impacts, particularly due to the lack of necessary survival skills during major disasters such as cyclones. The massive urbanisation and traditional land tenure systems affect local food security mainly on Funafuti Island [2], and majority of the land is held in customary ownership. The study participants indicated that the locals are not interested in traditional food-acquiring skills, which contributes

to increased food insecurity. This result was confirmed by Thaman et al. [30] and Sharma [31] which emphasised on the importance of traditional ecological knowledge to support sustainable food sources for local communities.

4.3. Economic vulnerabilities

The results highlighted that the Government of Tuvalu does not have sufficient financial capacity and heavily relies on foreign aid. Tuvalu Trust Fund (TTF), Falekaupule Trust Fund (FTF), fish licenses and remittances from migrant labour as well as international aid are the key sources of income for Tuvalu's government. The lack of government funding hinders national efforts to develop and implement climate change and food security related adaptation and mitigation activities. Dependency on foreign aid increases the social vulnerability of local communities to climate change risks. The heavy reliance on imported foods, mainly attributed to poor local economy, changing lifestyles and food preferences of the locals, also contributes to the vulnerable status of Tuvalu to climate change.

4.4. Built environment vulnerabilities

Due to the geology of Tuvalu and the limited land availability, the land resources are extremely limited. Land degradation, saltwater spray, extreme weathering, and uncontrolled earth extraction are some of the greatest threats for the country. The concentration of residential settlements and infrastructure along coastal areas has increased the

exposure to climate change risks such as coastal flooding, cyclones and storm surges. Total damages of the tropical cyclone Pam in 2015 are estimated at approximately US\$ 10.34 million, equivalent to 26.9% of Tuvalu's GDP [32].

Table 2 shows the opinions of participants about climate and food security related perception at the community level. More than 93% of participants "agree" or "strongly agree" that agriculture is influenced by climate change particularly by flooding and cyclones. 87% of participants confirmed that marine resources have been threatened by rising temperatures and ocean acidification.

These results have been confirmed by several studies that emphasized the highly vulnerable situation of Tuvalu to climate change ([33]; Taupo & Ilan, 2016; [9], [5,27]). The result shows that flood has been the main cause of food (in)security vulnerability causing damages to cultivated lands and water resources. Findings from the survey results on vulnerability to food (in)security due to climate change are categorised in four domains: natural environment, human, economy and built environment (Table 3).

5. Impacts of climate change on Tuvalu's food security

The collected data from locals and experts regarding climate change impacts on food security are interwoven due to the similarity in the results from literature review. Climate change impacts in Tuvalu such as sea levels rising, cyclones and droughts, and their cascading and

Table 2
Food security from the locals' perspective.

| Climate related stressors | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
|--|----------------|-------|---------|----------|-------------------|
| Tuvalu is vulnerable to the adverse impacts of climate change | 83% | 17% | 0% | 0% | 0% |
| Tuvalu has the capacity to cope and overcome the adverse impacts of climate change without the assistance of the international community | 3% | 10% | 4% | 33% | 50% |
| The effects of climate change are likely to be catastrophic in Tuvalu | 43% | 33% | 18% | 3% | 3% |
| Climate change associated natural disaster such as flood has frequently caused water shortage in Tuvalu | 23% | 40% | 17% | 17% | 3% |
| There is evidence that well water has been contaminated by ground water inundation due to sea level rise | 43% | 40% | 7% | 3% | 7% |
| Climate change affects farming activities in Tuvalu | 50% | 43% | 0% | 4% | 3% |
| Climate change (rising temperature and ocean acidification) threaten to affect Tuvalu's marine resource. | 50% | 37% | 10% | 0% | 3% |
| Climate change affects food security in Tuvalu | 63% | 30% | 4% | 0% | 3% |

compounding hazards such as coastal flooding, storm surges, saltwater intrusion and soil salinity have affected food (in)security severely.

5.1. Impact on landmass and arable lands

Coastal erosion has reduced the landmass of Tuvalu and caused the disappearance of Funafuti's small islets Pukavilivili and Vasafua and two small islets in the outer islands of Nukulaelae and Nukufetau. Sea level rise exacerbates the impacts of storm waves on atolls which causes severe coastal erosion and inundation of coastal areas [34]. Atoll nations may be uninhabitable to climate change within decades due. This phenomenon has degraded the turtle coastal habitat and affected local food source as turtle meat is traditionally a very important food in Tuvalu. Also, landmass reduction threatens the cultivation and indicates that Tuvalu's food security is at risk.

5.2. Impact on subsistence agriculture and home gardening

Coastal flooding and soil salination due to rising sea levels have adversely affected cultivated lands and non-resistant food plants such as bananas and breadfruits, and vegetable gardens along coastal areas in all islands of Tuvalu. King tides caused inland saltwater flooding in arable lands majority of the country. Storm surges during cyclones were identified as the threats for the less salt-water resistant food plants (bananas and breadfruit trees) and destroy pit plantations of pulaka. This insecurity lowers people's interest in engaging in farming activities, thus threatening local food security. In addition, the limited diversity of cultivated crops has hindered efforts to boost agricultural production.

The participants' perspective about the impacts of climate change on agriculture were confirmed by the Second National Communication [50] that stated the traditional crops such as pulaka are difficult to grow due to saltwater intrusion into the pits. Based on the Tuvalu's National Adaptation Programme of Action [51], king tides in February 2004 and 2006 flooded homes and about 40% of the airstrip, causing significant damage to pit grown root crops and bananas.

5.3. Impact on subsistence livestock farming

Livestock and poultry farming (including pigs, ducks and chickens) provides the only local and stable supply of meat for the local people. The results indicated that livestock farming has been limited due to the salinity of ground well water. The sheds for these domesticated animals are traditionally built along coastal areas which are adversely affected by coastal flooding, storm surges, and forceful winds.

5.4. Impact on water resources

There are no freshwater rivers or lakes in the country. Rainwater and groundwater found in underground lenses are the primary sources of freshwater in Tuvalu. In past few decades, Tuvaluans have experienced a freshwater shortage that has significantly affected cultivation. Saltwater intrusion due to rising sea levels has degraded ground well water. Also, the groundwater is contaminated by animal and human wastes. The participants claimed the salinity of both the ground well water and soil has increased during recent drought events and adversely affected agricultural land productivity. Apart from that, urbanisation is heavily impacting the freshwater availability in Tuvalu.

5.5. Impacts on local biodiversity

The recent prolonged droughts and extreme dry weather events have caused significant stress on food plants such as giant taro, bananas, and breadfruit. They prevented replenishment of coconut fruit and threatened key local foods such as coconut crabs and domesticated ducks.

The local participants indicated that the coastal erosion has affected the local plants habitats such as the *fetau* (*Calophyllum inophyllum*).

Table 3
Food security vulnerability in Tuvalu.

| Domain | Vulnerability factors | Vulnerability degree |
|---------------------|---|----------------------|
| Natural environment | Low-lying area Geographically small Isolated location Poor soil fertility Unfavourable climate for agriculture Limited vegetation types Poor natural resources | High |
| Social | Increasing population Internal migration (inter-island or rural-urban migration) Lack of human capacity/skilled personnel Lack of awareness about climate change Lack of traditional ecological or environmental knowledge Lack of traditional knowledge of preserving foods Changing diet or food preferences Cutting down of trees Removal of gravel and sands from coastal areas Traditional land tenure system | Moderate |
| Economic | Poor economy (no large-scale commercial farming and heavy reliance on imported foods) Heavy dependence on aid or relief assistance from the international community Lack of financial capacity Poor trading shipping service | High |
| Built environment | Location of houses and significant infrastructures along coastal areas Poor building codes or design Poor water collection and storage facilities Poor coastal defence or coastal protection measures Unreliable trading shipping services | High |

Fetau is one of the most important trees in Tuvalu as its blossoming indicates the best time to fish for the gatala (*epinephelus melanostigma*). It provides materials for building local canoes. Degrading the habitat of this tree severely threatens local food security in Tuvalu.

5.6. Impacts on marine resources

The local participants confirmed that cyclones, strong waves and increasing temperature of ocean water have caused the significant damage to coral reef habitats. The constant depletion of coral gradually decreases the number of marine species around coral reefs and poses a threat to food security. This is acknowledged by the prediction of decline in fish stock in the Pacific islands due to the adverse impact of rising sea surface temperature on coral reefs as a habitat for breeding and feeding of various marine species [35].

5.7. Impact on household finances and ability to pay for nutritious foods

Financial stability of households has been adversely affecting by climate change. For instance, unexpected dry events have caused water shortages which force people to pay for water. Given the low salary rate, spending money to buy water and nutritious foods including meat and vegetables put pressure on peoples' finances.

5.8. Interruption of trading shipping schedules due to extreme weather events

The delay of shipping schedules has been caused a food shortage due to high dependency on imported foods in Tuvalu. Cyclones and unexpected extreme strong winds are identified as the most important reasons for interruption of trading shipping schedules.

5.9. Flooding risk for food security in Tuvalu

Risk is assessed by analysing flood hazard exposure and the results of

food security vulnerabilities. Vulnerability of Tuvalu was assessed from the perspectives of the communities and local experts. The results of the vulnerability assessment in built environment indicated there is a high degree of vulnerability to cultivated lands and assets due to severe flooding events. Houses and significant infrastructures in coastal areas, water collection and storage facilities, poor coastal protection measures, and unreliable trading shipping services threaten the local and imported food sources.

Given the physical characteristics of Tuvalu such as low lying and geographically small, Funafuti (the capital) have been exposed to severe flood risk. Further, the increased sea level rise and destroying coral reefs are causing high sensitivity of coastal areas to the ocean wave energy and flooding events.

The risk assessment estimated the high risk of flooding events for the cultivated lands and assets particularly in the coastal areas of Tuvalu. This result is aligned with the research of Taupo & Noy [36] that indicated there is a high vulnerability of the livelihood among communities in Tuvalu when they are exposed to climate-related disasters such as cyclones.

6. Transformative adaptation to protect food (in)security

Tuvalu needs innovation and technology transfer to support its transformational adaptation efforts [37]. There is low institutional capacity and ineffective governance mechanism for effective implementation of adaptation measures. The Government is currently working on development of a National Adaptation Plan (NAP). The NAP needs to ensure a proper implementation and supporting its sectors. Based on our findings, adaptations options to enhance food security are proposed at community and government level (Table 4). These findings would be valuable inputs for the NAP development linking with Tuvalu Climate Change Policy [52].

The adaptation actions could be broadly categorised under five thematic areas:

Table 4
Adaptation in response to climate change impacts on food security.

| Community level | Government level |
|---|---|
| Community-based climate smart agricultural projects | Make food security a national priority at a policy level |
| Community-based climate change and food security related awareness raising/ training workshops | Secure funds for climate change and food security related projects and activities |
| Introduction of salt tolerant food plants or climate ready crops | Improve understanding of the impacts of climate change and food security |
| Use of engineered raised concrete <i>pulaka</i> pit gardens | Improve trading services |
| Relocate livestock farms inland to safer grounds | Coastal protection measures to reduce salt water intrusion and coastal inundation |
| Community- or island-based climate change and food security policy and plan | Prioritise, support and encourage food security related projects and activities |
| Community or island-based conservation areas | Reduce import tariffs |
| Revival of traditional food preservation and local diet | Improve national commitment |
| Community-based water projects | Improve national advocacy |
| Use of advanced farming techniques | Improve water storage facilities |
| Reaffirm traditional farming and fishing activities and traditional ecological knowledge | |
| Island council (Kaupule) to learn and adopt best food security enhancement practices from other countries | |

- **Community-based and led:** the effectiveness of the recommended strategies depends on the level of engagement and support from the local community;
- **Multi-sectoral:** the implementation of the above-mentioned strategies requires the involvement of many government agencies, national stakeholders and development partners from the international community;
- **Integrated:** the implementation of the proposed actions requires the simultaneous implementation of both structural and non-structural measures;
- **Capacity building:** the effective implementation of the proposed climate change adaptations and food security protection measures requires scaling-up or improvement in understanding the vulnerability context of Tuvalu to climate change;
- **Well communicated, planned, coordinated and adaptive:** the proposed actions, both at community and government levels should be well communicated, coordinated and adapted based on the continued situational assessment of climate change impacts and needs.

7. Discussions

Tuvalu's climate is generally unfavourable for agricultural activities and based on observed and projected climate changes, the majority of coastal cultivated land and assets will continue to be less productive due to a combination of sea level rise, soil salinization, coastal erosion, and flooding. Reduced freshwater availability, combined with increased salinity intrusion into groundwater, is likely to challenge the food security of Tuvaluans. The loss of habitats and sediment in the coastal areas due to flooding events will have adverse impacts on the natural coastal buffers to absorb wave energy and will exacerbate destroying the cultivated lands and assets. Increasing water temperature and ocean acidification will continue to be the key impacts of climate change on the marine environment. Degrading coral reefs as the main habitats for marine food sources will limit access to local protein sources and threaten food security in Tuvalu.

Low agricultural productivity and limited fishing in Tuvalu are mainly caused by characteristics of the physical environment (poor soil,

small and limited arable lands, poor vegetation types, and degraded biodiversity) and climate change impacts (flooding, soil salinization, erosion, increasing seawater temperature, and acidification), resulting in the exacerbation of existing situation of food insecurity. Increasing food price and high dependency on the imported food have caused economic vulnerability. Social vulnerability identified due to lack of knowledge about climate change and ecological issues, lack of traditional knowledge of preserving food (such as germinating the nut pit, salted and smoked fish, salted pork meat, and dripping from the pork), increasing inter-island migration (especially to Funafuti).

Cultivated lands and assets as the built environment are exposed to climate change impacts particularly flooding, and an increasing frequency and severity of flooding events will continue to occur given the projected changes in sea level rise by the 2090s in Tuvalu. Protecting Tuvalu's food security from the negative impacts of climate change will eventually lead to resilience of all sectors and thereby improved community resilience and food security status. Climate change action plan will help the community prepare for and respond to impacts on food security.

8. Conclusion and recommendations

Tuvalu may face impacts from climate change events such as floods, drought, and tropical cyclone and may pose imminent threat to its food security. Given the economic situation of Tuvalu, improving flood defences needs more international aids on research as well as coastal protection projects to support communities facing increasing risks of climate change into their food security. We recommend a framework to enhance food security through transformative adaptive pathway in local communities by improving access, utilisation, and availability of food (Fig. 3).

Structural approaches (such as engineered sea walls, levees, and breakwaters) and non-structural approaches (such as reefs, mangroves, dunes, and salt marshes) could be targeted both in key locations as well as over time to tackle the consequences of sea-level rise and to safeguard the coastal communities and their food. In 2016, the cabinet of Tuvalu endorsed the Tuvalu Infrastructure Strategy and Investment Plan (TISIP) (2016–2025) which falls under the Te Kakeega III, Tuvalu's National Strategy for Sustainable Development 2016–2020 (TKIII). TISIP includes projects to improve the development and operation of infrastructures of maritime, air, and land transportation, water and sanitation, waste management, energy, and health sectors. Implementing and maintaining the projects of TISIP (2016–2025) will in return improves the food security in Tuvalu. Also, developing and implementing the new agricultural policy will contribute to the food security. The policy needs to consider the customary laws and practices that are exercised in Tuvalu.

Accessing climate finance through multilateral and bilateral donor organisations will allow Tuvalu to implement projects that improve the food security and to adapt to the adverse impacts of the climate change. Several guidelines and literature are available for understanding the opportunities and challenges for accessing and mobilising climate finance in the Pacific island countries. Also, there are many guidelines (e.g., Pacific National Adaptation Plan (NAP) Guidelines) that are focused on strengthening access to climate finance. [38].

This study also proposes the concept of traditional food-acquiring skills and defines that this refers to all indigenous knowledge and skills that enable the local people to easily acquire food from local food sources through better utilisation of their traditional skills and locally available resources. These traditional skills include farming and fishing, traditional food preservation methods, and environmental or ecological knowledge of using, managing and sustaining local food sources.

Credit author statement

Bapon Fakhruddin: Conceptualization, Methodology, supervision, reviewing and editing.

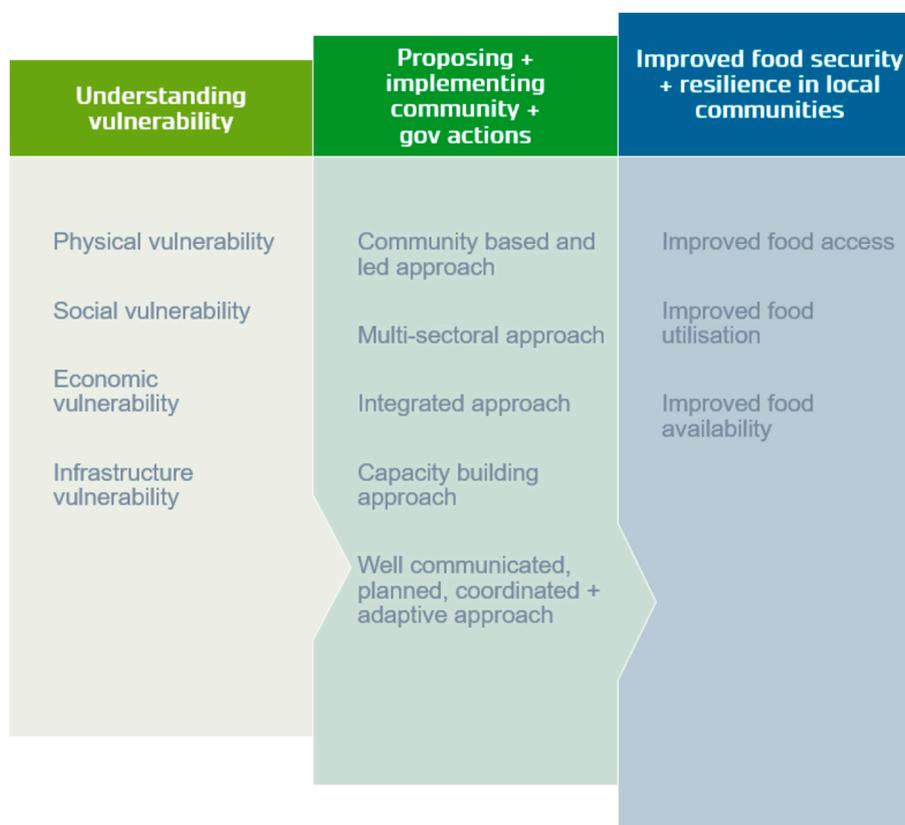


Fig. 3. Transformative adaptation framework for climate change and food security.

Saamu Tui.: Data collection, analysis, Writing- Original draft preparation.

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.

Data availability

Data will be made available on request.

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