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Conducting a Tailored and Localised Marine Heat Wave Risk Assessment for Vanuatu Fisheries

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Abstract: In Vanuatu, communities are predicted to be at high risk of more frequent and severe Marine Heat Wave (MHW) impacts in the future, as a result of climate change. A critical sector at risk in Vanuatu is fisheries, which vitally support food security and livelihoods. To sustain local communities, the MHW risk for Vanuatu fisheries must be extensively explored. In this study, an efficient MHW risk assessment methodology is demonstrated specifically for assessing MHW risk to Vanuatu fisheries. The fisheries specific MHW risk assessment was conducted on the local area council scale for two retrospective case study periods: 2015–2017 and 2020–2022. An integrated GIS-based approach was taken to calculating and mapping monthly hazard, vulnerability, exposure, and overall risk indices. Key areas and time periods of concern for MHW impacts are identified. Area councils in the Shefa province area are particularly concerning, displaying consistently high-risk levels throughout both case studies. Risk levels in 2022 were the most concerning, with most months displaying peak risk to MHW impacts. A sensitivity analysis is employed to validate the selection and weighting of the indicators used. However, it is recommended that a more comprehensive validation of the retrospective risk assessment results, using multiple ground-truth sources, be conducted in the future. Once results are sufficiently validated, management recommendations for fisheries resilience can be made.

Keywords: Marine Heat Waves; risk assessment; climate change; Small Island Developing States; Vanuatu

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1. Introduction

1.1. Marine Heat Waves in Vanuatu Fisheries

A Marine Heat Wave (MHW) can be described as a spatial area with a prolonged and extremely warm sea surface temperature (SST), which can persist for days or months [1]. Such events affect vulnerable coastal communities throughout the world, particularly Small Island Developing States (SIDS) in the Pacific, namely Vanuatu [2]. MHW events occurring around Vanuatu are generally driven by the following climatic phenomena: El-Niño–Southern Oscillation (ENSO) [1,3], Interdecadal Pacific Oscillation (IPO), North Pacific Gyre Oscillation (NPGO), and Pacific Decadal Oscillation (PDO) [4]. ENSO is seen as the dominant driver of MHWs across Vanuatu. The El Niño phase is associated with stronger MHWs in the central and eastern Pacific Ocean, and the La Niña phase is associated with stronger MHWs in the south, north, and western Pacific Ocean [4].

MHW events are known to have dramatic impacts; specifically, the ecological impacts of MHWs can be devastating and can result in negative flow-effects for all sectors of a community. Coral bleaching, fish kills, and species range shifts are some of the more significant ecological impacts known to occur as a result of MHWs [4]. Such MHW impacts commonly detriment various aspects of Vanuatu communities but can especially affect the fisheries sector [4].

Fisheries is a critical sector for Vanuatu communities, providing key food and livelihood sources [5]. Particularly in rural Vanuatu communities, most people rely on subsistence fishing as their main source of income and protein. For the country overall, inshore and offshore fisheries comprise the biggest exports [6]. Hence, it is vital that fisheries supplies are sustained in Vanuatu [5]. The fisheries sector in Vanuatu is at risk from various natural hazards, including tropical cyclones, drought, earthquakes, and MHWs. Each of these natural hazards has been known to damage marine environments and fisheries in Vanuatu. In some cases (e.g., Tropical Cyclone Pam and the El Niño induced drought of 2015), these hazards have occurred simultaneously, creating highly concerning conditions for Vanuatu fisheries [5]. Compared to the other hazards that threaten fisheries throughout Vanuatu, the impacts of MHWs have been disproportionally investigated [4].

Dunstan et al. [7] have observed fisheries to experience severe impacts from past MHW events, often resulting in long-term damage to the entire fisheries sector. Such impact is likely due to the ecological damage which MHWs are known to cause [8]. With Vanuatu communities having low capacity to adapt (due to geographical limitations, lower levels of economic development, and limited resources), it is critical that future MHW impacts are prepared for and managed efficiently [9,10]. The impact of MHWs on Pacific Island fisheries has only recently come to be of focus in research, thus our understanding on the link between MHWs and impacts on Pacific Island fisheries is still limited. Further investigation is required to ensure fisheries resilience throughout future MHW events [4].

1.2. Fisheries Risk Management in Vanuatu through Marine Heat Wave Risk Assessment

In the context of MHWs, risk management refers to a combined approach of risk assessment, implementation of management actions to control, reduce and transfer risks, and handling uncertainty to reduce the potential for loss and harm. Efficient MHW risk assessment is therefore a critical method contributing to efficient MHW risk management [1,3]. Such an assessment would examine three main components of disaster risk: hazard, vulnerability, and exposure [11]. Hazard, vulnerability, and exposure are recognised globally in disaster risk assessment studies as the key factors underpinning risk [12,13]. Hazard is described as the climatic disturbances' characteristic of a MHW event which may cause damage to the livelihoods, resources, and environment in a certain area [14]. Vulnerability is seen as how much the livelihoods, resources and environment of a certain area are susceptible to being affected when MHW impacts occur [15]. Exposure refers to the actual livelihoods, resources, and environment of a population in a specific area where a MHW event may occur [15]. Resilience, defined as the capacity to resist and recover from losses, is another factor increasingly recognised as key to MHW risk [16]. Resilience can be considered in risk assessment studies as a contributing index or through the dissemination of risk assessment results to decision-makers to foster resilience, specifically informing resilient risk management strategies [16].

Literature recognises that for efficiency, a MHW risk assessment is required to dynamically assess the spatial and temporal components of MHWs, investigating hazard, vulnerability and exposure on the most localised scale for specific time periods [14]; be tailored to specifically estimate MHW risk in a particular area and output user-specific risk information [17,18]; incorporate both ecological and human indicators [1,19], and calculate risk indices and produce risk maps using integrated GIS-based techniques [20].

Although these components are commonly recognised as key for efficiency, such methods are lacking in past MHW risk assessments not only in Vanuatu, but across most studies on Pacific SIDS [10,21,22]. Aitkenhead et al. [11] aimed at making strides to address these knowledge gaps, specifically focusing on exploring the first two steps of an efficient MHW risk assessment methodology, tailored indicator selection and weighting, applied to the context of assessing MHW risk to fisheries in Vanuatu. The study implemented a user-centered approach to select tailored hazard, vulnerability, and exposure indicators that would be appropriate in assessing MHW risk to Vanuatu fisheries (Table 1). The approach by Aitkenhead et al. [11] is novel in conducting the process of tailored indicator selection, specifically for indicating MHW risk in Vanuatu fisheries. Other risk assessment studies previously conducted for Vanuatu have commonly used generalised indicators, without specific relation to a certain sector. In the case of Bell et al. [21], a fisheries risk assessment was conducted using fisheries-specific indicators (with a heightened focus on tuna), however risk was considered in terms of all natural hazard impacts, rather than for MHW-specific impacts.

Table 1. List of indicators selected by Aitkenhead et al. [11] for use in a fishery based MHW risk assessment in Vanuatu.

Index	Indicator
Hazard	Sea Surface Temperature (SST) Coral bleaching Chlorophyll-a concentration
Vulnerability	Terrestrial-based food and income generation Fishing skills and technology Fishery fish diversity and fishery flexibility Primary production of commercial fisheries
Exposure	Seagrass population and C content Coral Habitat Health and Crown of Thorns Prevalence Crab stock health Fish mortality and fish stock health

As per Wang et al. [23], the next steps in developing an efficient MHW risk assessment methodology to analyse fisheries-based risk in Vanuatu would include data collection, index calculation, and index mapping. Following this, risk validation would occur (Figure 1).

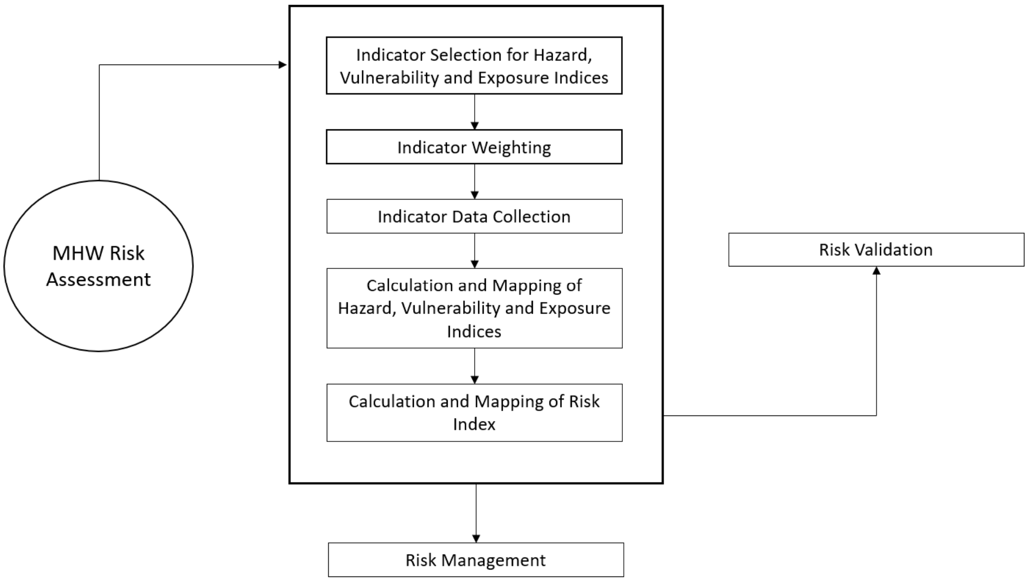


Figure 1. The key steps involved in the MHW risk assessment methodology. This figure is adapted from Wang et al. [23].

1.3. Aims and Objectives

Accordingly, this study aims to conduct the next steps in developing and conducting an efficient, fisheries-based MHW risk assessment in Vanuatu. Specifically, this study will complete data collection for the indicators proposed by Aitkenhead et al. [11], calculate hazard, vulnerability, exposure, and risk indices for retrospective time periods, and produce GIS-based MHW hazard, vulnerability, exposure, and risk maps displaying retrospective risk assessment results. It is intended that this study complete a fishery-focused MHW risk assessment for retrospective years (a period from 2015–2017 and a period from 2020–2022) on the most localised level as data will allow. This assessment would have the potential to reveal any previous occurrences of MHW events throughout Vanuatu that impacted fisheries and demonstrate the ability of an efficient MHW risk assessment methodology to signal risk levels for different local areas when transitioning into and out of MHW events.

In completing these aims and objectives, this research will address the following research questions:

1. Can an integrated and tailored risk assessment methodology accurately indicate disaster risk for MHWs within Vanuatu before a disaster event occurs?
2. How can expanding risk knowledge through risk assessment lessen the specific sectoral impacts of MHWs in the fisheries sector of Vanuatu?

2. Materials and Methods

2.1. Study Area

Vanuatu is a country in the western South Pacific Ocean consisting of approximately 80 islands, totalling a land area of 12,335 km^2. There are six provinces of Vanuatu, with many local area councils spread throughout each of these: Torba, Sanma, Penama, Malampa, Shefa, and Tafea (Figures 2 and 3). Vanuatu is considered a SIDS, meaning it is a developing small island country facing sustainable development challenges [9]. Vanuatu is mainly made up of coastal communities [9]. The climate is tropical and cycles through two distinct seasons—a warm, wet season and a cool, dry season. Climatic variability is mainly driven by ENSO [1,3]. Under increasing climate change, it is expected that air and sea surface temperatures will rise in Vanuatu, as well as the occurrence of altered rainfall patterns, sea level rises, and ocean acidification [9]. The Vanuatu economy is supported by three key sectors: tourism, agriculture, and fisheries. Fisheries, in particular, play a vital role in maintaining food security in Vanuatu communities [5]. Vanuatu has a history of malnutrition; thus, food security is essential to the resilience of Vanuatu communities [9].

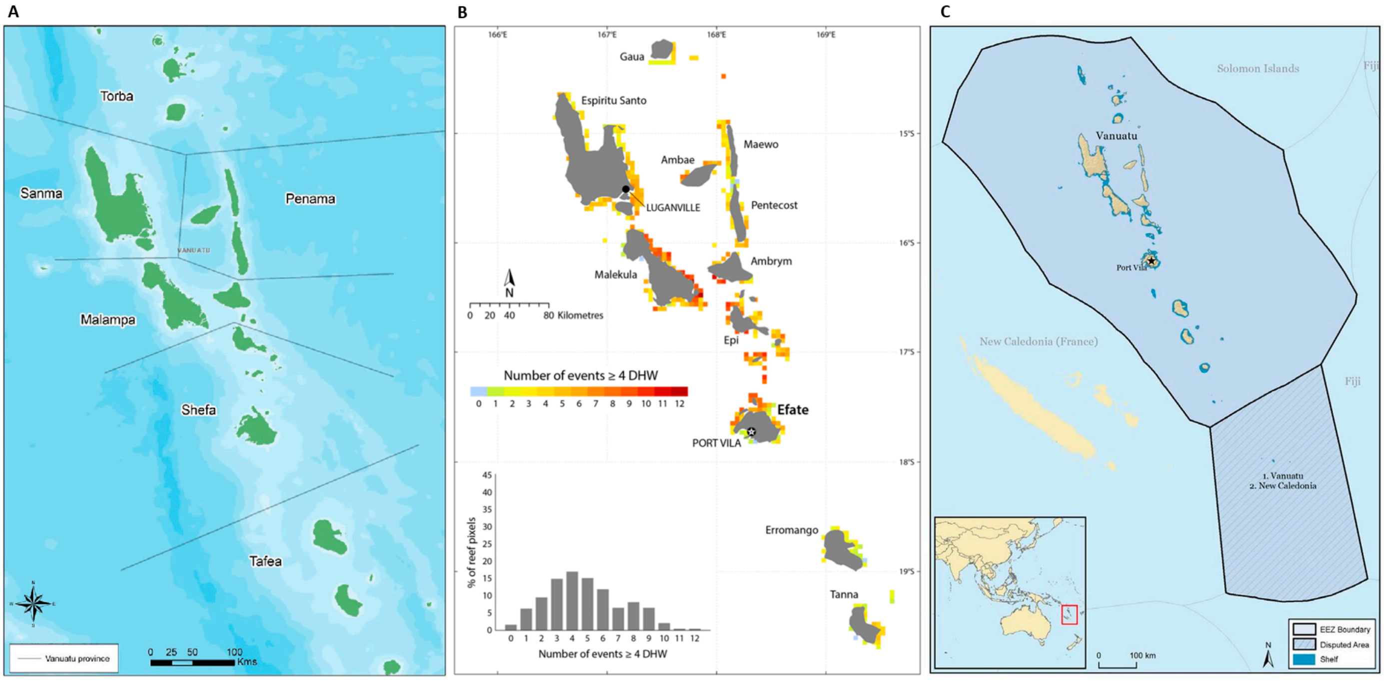
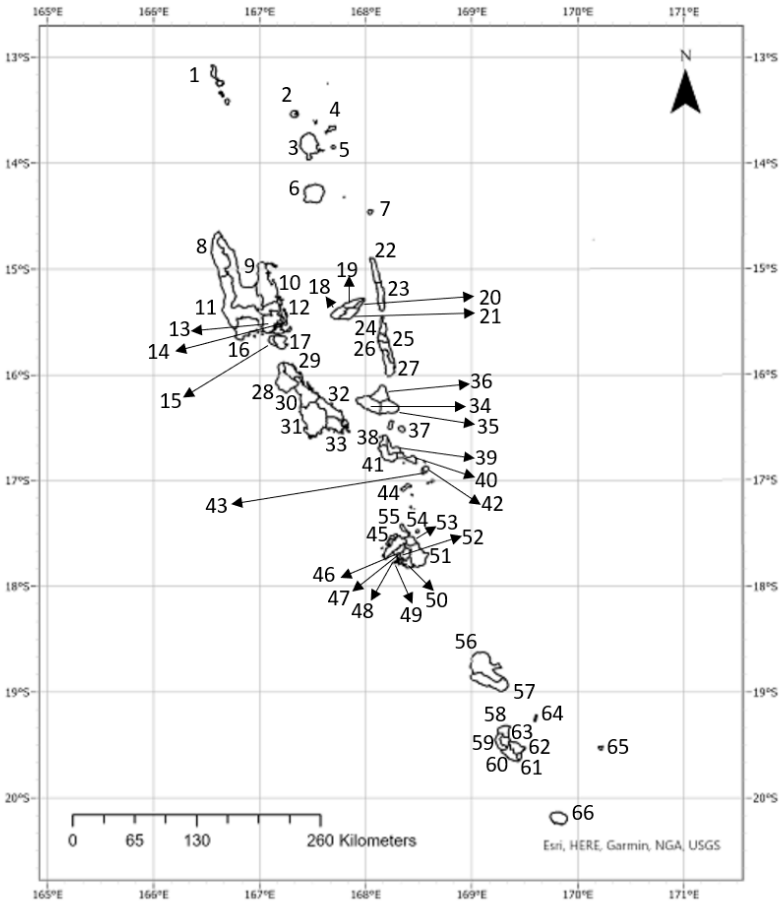


Figure 2. A series of maps for Vanuatu. Map (**A**) shows a Vanuatu administrative map with each of the six provinces displayed (Malampa, Penama, Sanma, Shefa, Tafea, and Torba) and includes a zoomed-out view of where Vanuatu is located in the Pacific Islands [24]. Map (**B**) gives a spatial thermal history for Vanuatu in terms of Degree Heating Weeks (DHWs) [25]. Map (**C**) displays the Exclusive Economic Zone (EEZ) boundaries for Vanuatu [26].



1. Torres
2. Ureparapara
3. Vanua Lava
4. Motalava
5. Mota
6. Gaua
7. Merelava
8. North West Santo
9. North Santo
10. East Santo
11. West Santo
12. South East Santo
13. Canal-Fanafo
14. Luganville
15. West Malo
16. South Santo
17. East Malo
18. West Ambae
19. North Ambae
20. East Ambae
21. South Ambae
22. North Maewo
23. South Maewo
24. North Pentecost
25. Central Pentecost 1
26. Central Pentecost 2
27. South Pentecost
28. North West Malekula
29. North East Malekula
30. Central Malekula
31. South West Malekula
32. South East Malekula
33. South Malekula
34. West Ambrym
35. South East Ambrym
36. North Ambrym
37. Paama
38. Vermali
39. Varisu
40. South Epi
41. Vermaul
42. North Tongoa
43. Tongariki
44. Makimae
45. Maloura
46. Mele
47. Port Vila
48. Pango
49. Ifira
50. Eratap
51. Eton
52. Erakor
53. North Efate
54. Emau
55. Nguna
56. North Erromango
57. South Erromango
58. North Tanna
59. West Tanna
60. South West Tanna
61. South Tanna
62. Whitesands
63. Middle Bush Tanna
64. Aniwa
65. Futuna
66. Aneityum

Figure 3. List and display of the 66 local area councils spread throughout Vanuatu. Basemap gathered from Esri [27].

2.2. Study Design

In this study, we regard a MHW event as the experience of hazardous MHW conditions with corresponding impacts. The MHW risk assessment of this study is conducted at the area council level for two case studies using retrospective time periods. The use of two retrospective time periods suits the needs of this study, as it aims to provide a demonstration of how an efficient MHW risk assessment methodology could be applied to the context of MHW risk to fisheries in Vanuatu to signal risk levels in periods of no MHWs, during MHWs, and the transitional periods in between. For a successful case study, the retrospective period chosen was required to be one in which data was available for hazards, vulnerability, and exposure indicators, be one in which MHW conditions are known to have occurred, and to be long enough to cover a time with no MHW conditions, transition into a MHW during the height of a MHW, and transition out of a MHW. 2015–2017 and 2020–2022 fit these requirements. It is widely known that a MHW event occurred across the Pacific SIDS throughout 2016 [4]. Several more recent events have also been suspected to have occurred throughout the western South Pacific Ocean around 2020 and 2022 [28].

The methodology developed in this study uses best practice techniques to complete the next steps in an efficient MHW risk assessment, following on from earlier studies [11]. In this study, indicator data collection, calculation, and mapping of dynamic, hazard, vulnerability, and exposure indices, and the production of an overall MHW risk index are performed in the context of a retrospective MHW risk assessment for fisheries in Vanuatu. It is important to note that, although outlined in Figure 1 as another step in efficient MHW risk assessment methodology, a complete investigation of risk validation is beyond the scope of this paper. Preliminary validation is conducted in the form of sensitivity analysis, but a more comprehensive validation of the MHW risk assessment for fisheries in Vanuatu is required in the future [29].

Hazard, vulnerability, and exposure components are considered equally in this methodology. Consideration of resilience is beyond the scope of this study but is recommended for future investigation in terms of using the results of this study to inform more resilient MHW risk management for fisheries in Vanuatu. Both the spatial and temporal aspects of MHWs are investigated using retrospective dynamic and semi-dynamic data. As such, the risk assessment is thought of as 'semi-dynamic' with all hazard indicator data being updated at regular intervals (hazard indicator data is updated as regularly as daily, but monthly mean data for each hazard indicator is used in this study to assess risk on a monthly time scale), some exposure and vulnerability data updated yearly, and other exposure and vulnerability indicators being entirely static.

2.2.1. Indicator Data Collection

The risk indicators selected for incorporation in the hazard, vulnerability, and exposure index calculations were based on the findings from earlier studies [11]. The MHW hazard indicators were selected to cover the possible occurrence of future MHW events [14]. The MHW vulnerability indicators were chosen to consider the tendency of exposed factors to suffer adverse impacts when a MHW event does occur [15]. MHW exposure indicators were selected to reflect the total population, its livelihoods, and assets in a specific area in which MHW events occur [15]. These definitions are kept consistent throughout the overall MHW risk assessment process.

Minor adjustments were made to the selected indicators to ensure that appropriate data could be found and used in this study. Table 2 displays the slightly adjusted list of indicators chosen for use in this study, along with the data source for each indicator and the spatial and temporal extent of the available indicator data. The smallest possible spatial and temporal scale was used for each indicator. As data availability is commonly scarce in Pacific SIDS namely Vanuatu, some indicators displayed only static or yearly data, with the provincial scale being the smallest spatial scale for some indicators.

Table 2. Selected indicators to be used in the MHW risk assessment calculation, with details provided for the data source, spatial scale, and temporal scale of the indicator data collected for use in this study.

Index	Proposed Indicator from Aitkenhead et al. [11]	The Actual Indicator Used in This Study	Data Source	Spatial Scale	Temporal Scale
Hazard	SST	Mean Sea Surface Temperature Anomaly	NOAA THREDDS Server	Averaged satellite-based ocean data to the area council level	Monthly
	Coral Bleaching	Coral Bleaching Alert Area	NOAA THREDDS Server	Averaged satellite-based ocean data to the area council level	Monthly
	Chlorophyll-a Concentration	Chlorophyll-a Concentration	Pacific Ocean Portal	Averaged satellite-based ocean data to the area council level	Monthly
Vulnerability	Terrestrial (land)-based food and income generation	Percentage of households growing crops or owning livestock for food and income generation	Vanuatu National Statistics Office	Area council	Yearly
	Fishing skills and technology	Number of people required to sufficiently increase fishery skills and technology in each area	Australian Aid Province Skills Plan	Provincial	Yearly
	Fishery fish diversity and fishery flexibility	Number of fishery resources fished	Vanuatu National Biodiversity Strategy and Action Plan	Provincial	Yearly
	Primary production of commercial fisheries	Commercial fisheries annual added value (USD)	National Marine Ecosystem Service Valuation	Provincial	Yearly

Table 2. *Cont.*

Index	Proposed Indicator from Aitkenhead et al. [11]	The Actual Indicator Used in This Study	Data Source	Spatial Scale	Temporal Scale
Exposure	Seagrass population and C content	Seagrass species richness (number of observed seagrass species)	McKenzie et al. [30]	Area council	Static
	Coral Habitat Health and Crown of Thorns Prevalence	Crown of Thorns Prevalence Score (none—0, low—1, medium—2, high—3)	Dumas et al. [31]	Area council	Yearly
	Crab stock health	Stock status score for Coconut Crab (0—no noted population, 1—overfished, 2—unstable, 3—stable, 4—underfished)	Vanuatu National Coconut Crab Fishery Management Plan	Area council	Yearly
	Fish mortality and fish stock health	Fish catch score (based on the fishing of tuna and billfishes by the fleets of Vanuatu) (1–7 low to high catch)	Food and Agriculture Organisation of the United Nations (FAO) FishStat database [22].	Area council	Yearly

It is important to note that the selected indicators were specifically chosen to reflect MHW risk to the fisheries sector; publicly accessible data was only available for certain indicators as data availability is relatively poor across Vanuatu (all indicators ultimately selected for use in the risk assessment had publicly accessible data available), thus indicators which may have been more appropriate for use were omitted; indicator data was only available at certain spatial resolutions, so in some cases where provincial data was only available, the same value was repeated for all area councils in each province.; and space-based monitoring products were used when collecting data for the MHW hazard indicators to make sure accuracy was achieved. It is widely known that space-based monitoring products are highly accurate, and the use of such products should be increased when monitoring climate extremes in future disaster risk investigations [32].

All the selected hazard, vulnerability, and exposure indicators to be used in the MHW risk assessment have differing standard thresholds for signalling the different strengths of MHW events. Table 3 shows the standard thresholds for each indicator used in this study. These thresholds were established according to their use in past studies [11,33], the advice of the Vanuatu Meteorological and Geohazards Department (VMGD), and past data trends. The different thresholds are sorted according to the likely signal of ‘no to mild MHW risk’, ‘moderate MHW risk’, or ‘severe to extreme MHW risk’. The thresholds displayed in Table 3 were not utilised in any of the index calculations in our study, they are displayed here only for insight into the standard signals likely given by each range of values in the indicator data.

Table 3. Indicator thresholds that signal different stages of MHW risk.

Index	Indicator	No to Mild MHW Risk	Moderate MHW Risk	Severe to Extreme MHW Risk
Hazard	Mean Sea Surface Temperature Anomaly	0 °C and under	1–2 °C	Above 2 °C
	Coral Bleaching Alert Area	0	1–2	3–4
	Chlorophyll-a Concentration	Above 0.15	0.06 to 0.15	0 to 0.05
Vulnerability	Percentage of households growing crops or owning livestock for food and income generation	90% to 100%	75% to 90%	Below 75%
	Number of people required to sufficiently increase fishery skills and technology in each area	250 and under	250–450	450 and above
	Number of fishery resources fished	20 and above	15 to 19	0 to 14
	Commercial fisheries annual added value	$1,500,001 and above	$1,000,001 to $1,500,000	0 to $1,000,000
Exposure	Seagrass species richness	7 and above	4 to 6	0 to 3
	Crown of Thorns Prevalence Score	0	1	2 to 3
	Stock status score for Coconut Crab	3 to 4	2	0 to 1
	Fish catch score	6 to 7	4 to 5	1 to 3

2.2.2. Calculation and Mapping of Hazard, Vulnerability, and Exposure Indices

Data was mapped on the area council scale for each month in the 2015–2017 and 2020–2022 periods for the hazard index and for each year in the 2015–2017 and 2020–2022 periods for vulnerability and exposure indices (as exposure and vulnerability indicator data is only static or updated yearly). For the 2015–2017 case study period, index maps were produced for the 66 area councils across Vanuatu. Area council boundaries were amended by the Vanuatu Government recently (VNSO); however, the boundary data is not yet available, so the 2020–2022 maps were produced using the 66 area councils as in the 2015–2017 case study period. All maps produced in this study used the same base map from the open-sourced platform GISMap.

Integrated-GIS methodology for calculation and mapping (which includes three key components: data integration into GIS; assigning of risk assessment tasks; and consideration of risk decision-making [20]) was used to produce and display monthly index levels for 2015–2017 and for 2020–2022, on the area council scale across Vanuatu. Indicator data was first reclassified on a 1–10 scale by a linear function through the rescale by function tool in ArcGIS Pro (version 3.0.3) [27]. Data for each indicator was then standardised with fuzzy logic (using the fuzzy membership tool in ArcGIS Pro). Fuzzy logic applies a fuzzy membership class to data, describing the relationship between it and MHW risk [34]. Fuzzy values are produced on a 0–1 scale based on the likelihood that the indicator data contributes to MHW risk. A value of 0 is assigned to indicator data unlikely to be associated with MHW risk. A value of 1 is assigned to indicator data most likely to be associated with MHW risk. Equation (1) displays the mathematical process behind fuzzy logic in GIS [34].

$$\mu A(x) : X \longrightarrow [0,1] \tag{1}$$

where $\mu A(x)$ refers to the grade of membership for element x in a fuzzy set A, and X is the universal set.

In this study, two classes of fuzzy membership were applied: fuzzy small and fuzzy large. Fuzzy small was used when smaller data values have a higher likelihood of influencing MHW risk. Fuzzy large was used when larger data values have a higher likelihood of influencing MHW risk. Accordingly, with fuzzy large, greater data values, membership values are assigned closer to 1, and with fuzzy small, smaller data values, membership values are assigned closer to 1. Both transformation functions are defined by a midpoint value that can be left as a default in ArcGIS Pro (version 3.0.3) or can be changed manually to ensure it is most appropriate for the specific dataset being standardised. In this study, we altered the midpoint manually when running the fuzzy membership function. The midpoint used when standardising each indicator was based on the average data value expressed in historical data records. This allowed for the data to be standardised both spatially and temporally.

The mathematical process for the fuzzy large membership function is displayed in Equation (2), and the mathematical process for the fuzzy small membership function is displayed in Equation (3) [34].

$$\mu(x) = \frac{1}{1 + \left(\frac{x}{f2}\right)^{-f1}} \tag{2}$$

$$\mu(x) = \frac{1}{1 + \left(\frac{x}{f2}\right)^{f1}} \tag{3}$$

where f1 is the spread and f2 is the assigned midpoint.

The fuzzy membership class assigned to each indicator is displayed in Table 4.

Each indicator in the hazard, vulnerability, and exposure index were mapped on the area council scale as monthly and yearly raster layers in ArcGIS Pro (version 3.0.3). Following indicator data standardisation, numerical weights were applied to each indicator based on those recommended by [11]. Aitkenhead et al. [11] used a locally informed rank-based weighting method to assign the indicator weights. This is a common method used for indicator weighting in disaster risk assessment [35], which utilises the perspectives of locals in the area of study to rank risk assessment indicators. Indicator rankings then inform the weights applied to each indicator. This method is described as a semi-quantitative approach that is simple to apply, accounts for data scarcity, and has been known to be effective, particularly on regional scales [23]. Some may argue that the weights assigned by this process will be subjective; however, local perspectives commonly depend upon extensive experience and valuable local knowledge that can be greatly informative [36].

Table 4. Fuzzy membership classes assigned to each indicator in the hazard, vulnerability, and exposure indices.

Index	Indicator	Fuzzy Membership Class
Hazard	Mean Sea Surface Temperature Anomaly	Large
	Coral Bleaching Alert Area	Large
	Chlorophyll-a Concentration	Small
Vulnerability	Percentage of households growing crops or owning livestock for food and income generation	Small
	Number of people required to sufficiently increase fishery skills and technology in each area	Large
	Number of fishery resources fished	Small
	Commercial fisheries annual added value	Small
Exposure	Seagrass species richness	Small
	Crown of Thorns Prevalence Score	Large
	Stock status score for Coconut Crab	Small
	Fish catch score	Small

The weights assigned to each hazard, vulnerability, and exposure indicator in this study are shown in Table 5. These weights reflect the respective significance and influence of each indicator on the relative index that it contributes to. Weights were produced on a 0–1 scale where 0 indicates no likely influence of the indicator on the overall hazard, vulnerability, or exposure index which it informs, and 1 indicates total likely influence of the indicator on the overall hazard, vulnerability, or exposure index which it informs [37].

Table 5. Indicator weights.

Index	Indicator	Proposed Weight
Hazard	Mean Sea Surface Temperature Anomaly	0.50
	Coral Bleaching Alert Area	0.30
	Chlorophyll-a Concentration	0.20
Vulnerability	Percentage of households growing crops or owning livestock for food and income generation	0.35
	The number of people required to sufficiently increase fishery skills and technology in each area	0.10
	Number of fishery resources fished	0.30
	Commercial fisheries annual added value	0.25
Exposure	Seagrass species richness	0.35
	Crown of Thorns Prevalence Score	0.30
	Stock status score for Coconut Crab	0.10
	Fish catch score	0.25

The standardised indicator raster layers were used to calculate the vulnerability, hazard, and exposure indices. The raster calculator function in ArcGIS Pro (version 3.0.3) was used to calculate the indices, following Equations (4)–(6). Vulnerability and exposure indices were calculated and mapped for each year being investigated. A hazard index was calculated and mapped for each month being investigated.

$$\mathrm{HI} = \sum_{i=1}^{n} \left(w_i * x_i'\right) \tag{4}$$

$$\mathrm{VI} = \sum_{i=1}^{n} \left(w_i * x_i'\right) \tag{5}$$

$$\mathrm{EI} = \sum_{i=1}^{n} \left(w_i * x_i'\right) \tag{6}$$

where HI is the Hazard Index, VI is the Vulnerability Index, EI is the Exposure Index, n is the number of indicators, x_i' refers to the standardised indicators, and w_i refers to indicator weight.

2.2.3. Calculation and Mapping of the MHW Risk Index

To calculate and map the final MHW risk index value for each area council across the study period, the MHW hazard, vulnerability, and exposure index maps were integrated. This was calculated through the Fuzzy Gamma Overlay function in ArcGIS Pro (version 3.0.3) (with a gamma of 0.75). The mathematical expression for the fuzzy gamma overlay function is presented by Equation (7).

$$\mu_{\text{gamma}} = (\mu_{\text{sum}})^{\gamma} \times \left(\mu_{\text{product}}\right)^{1-\gamma} \tag{7}$$

where μ_{gamma} is the calculated fuzzy membership function, γ is a parameter chosen between 0 and 1; μ_{sum} is the fuzzy algebraic sum, and μ_{product} is the fuzzy algebraic product.

The mathematical processes of fuzzy sum, and fuzzy product are additionally given below in Equations (8) and (9), respectively.

$$\mu_{\text{sum}} = 1 - \prod\nolimits_{i=1}^{n} (1 - \mu_i) \tag{8}$$

$$\mu_{\text{product}} = 1 - \prod\nolimits_{i=1}^{n} (\mu_i) \tag{9}$$

where μ_i is the fuzzy membership, and i equals the number of maps to be overlayed. In the fuzzy gamma process, γ = 0 is equivalent to the fuzzy product and γ = 1 is equivalent to the fuzzy sum.

The MHW risk levels displayed in the final MHW risk maps were categorised into five severity classes commonly used in disaster risk assessment studies [37]:

1. Very mild (includes all index values from 0.01–0.20)
2. Mild (includes all index values from 0.21–0.40)
3. Moderate (includes all index values from 0.41–0.60)
4. Severe (includes all index values from 0.61–0.80)
5. Extreme (includes all index values from 0.81–1.00)

2.2.4. Performance of Sensitivity Analysis

The sensitivity of each of the hazard, vulnerability, and exposure indices to the different indicators that inform them was tested. Sensitivity analysis examines how much of the change in an output (in this case the hazard, vulnerability, or exposure index) is apportioned, qualitatively or quantitatively, to variation in each of its inputs (in this case the different indicators that inform each index) [38]. This can signal the 'robustness' of each indicator used and identify priority needs for the revision of the weighting scheme applied to each indicator.

Sensitivity testing was conducted across two example area councils: Makimae (representing area councils commonly of higher risk) and West Tanna (representing area councils commonly of lower risk). For hazard sensitivity testing, area council data was tested for a month of high risk (April 2022) and a month of low risk (September 2021). For vulnerability and exposure sensitivity testing, area council data was tested for a year of high risk (2016) and a year of low risk (2021).

The sensitivity analysis conducted in this research was a one-way analysis. Accordingly, a specific parameter (in this case, one of the indicators used in this research) used in the calculation of a specific output (in this case, the hazard, vulnerability, or exposure index) was varied incrementally to examine the effect on the output value. This is independently repeated for each indicator. For example, hazard index sensitivity was tested against changes in SST, then against changes in BAA, and finally against changes in Chlorophyll-a concentration.

The one-way sensitivity analysis was conducted using the what-if function in Microsoft excel. To perform the what-if function, a data table was first created. In the data table, the original output value for the period of investigation was included. The value of each indicator under investigation was then altered in a stepwise manner (from 0.1 to 1) using 0.1 increments. An output value was produced for each incremental value and was included in the data table. An example data table has been provided in Table A1. The output values depicted in the data table were used to calculate the Sensitivity Index (SI). The SI indicated the sensitivity of the index in question to the individual indicator under investigation as per Equation (10) (adapted from Farok and Homayouni [39]).

$$\mathrm{SI} = (\mathrm{D}_{\mathrm{max}} - \mathrm{D}_{\mathrm{min}})/\mathrm{D}_{\mathrm{max}} \tag{10}$$

where $\mathrm{D}_{\mathrm{max}}$ is the output result (hazard, vulnerability, or exposure value) when the indicator value in question is set at its maximum value and $\mathrm{D}_{\mathrm{min}}$ is the result for the minimum indicator value.

The SI, as described in Equation (10), represents how big the change in the index value is in response to the changes in the indicator value. This gives insight into how sensitive the index under investigation is to changes in the indicator under investigation. A high SI means high sensitivity, and vice versa, with ‘sensitivity’ meaning the extent to which the index under investigation reacts to changes in the data of the specific indicator under investigation. In this research, we classify high sensitivity as an SI of 0.80–1.00.

3. Results

3.1. 2015–2017 Case Study Results

3.1.1. Hazard, Vulnerability, and Exposure

In each year of 2015, 2016, and 2017, hazard levels fluctuated greatly from month to month. In all years when hazard levels peaked throughout the country, levels tended to be greater in the central and southern regions (Figures 4–6). In all three years, concerning hazard levels were noticed at the beginning of the year, from January to April. Other months of concern differed from year to year. For example, between 2015 and 2016, December was a peak hazard month with high levels noticed in Santo Island (with West Santo at severe hazard), whereas in 2017 no severe hazard levels were seen throughout Vanuatu (Figures 4–6). Overall, 2016 was the highest hazard year in which severe hazard levels were commonly seen throughout Vanuatu from January to May, as well as some severe hazard in December (Figure 5).

In 2015, 2016, and 2017, the following local area councils were the most concerning in terms of vulnerability, with severe levels: Gaua, Ureparapara, Torres, Merelava, Southwest Malekula, North Tongoa, Tongariki, and Nguna (Figure 7). These are local area councils spread between Torba, Malampa, and Shefa provinces. Vulnerability levels did not change across the years, except in the case of North Tanna. In 2015, North Tanna displayed moderate vulnerability, which changed to mild in 2016 and 2017 (Figure 7).

There were more severely exposed than vulnerable area councils through 2015–2017, with East Santo, Canal-Fanafo, South Santo, East Malo, Southeast Malekula, Makimae, Mele, Ifira, Pango, and Port Vila at severe exposure levels in all three years (Figure 8). Exposure levels changed for some provinces throughout 2015–2017. South Tanna changed from very mild exposure in 2015, to mild in 2016, and then back to very mild in 2017. Similarly, West Ambae changed from mild exposure in 2015 to moderate in 2016, and then back to mild in 2017. North Maewo displayed moderate exposure in 2015, which escalated to severe in 2016, and then dropped back to moderate in 2017. In Nguna, exposure was shown as mild in 2015, which seemed to lessen in 2016 and 2017, with very mild levels displayed. Overall, area councils were more exposed in 2016 than in 2015 or 2017 (Figure 8).

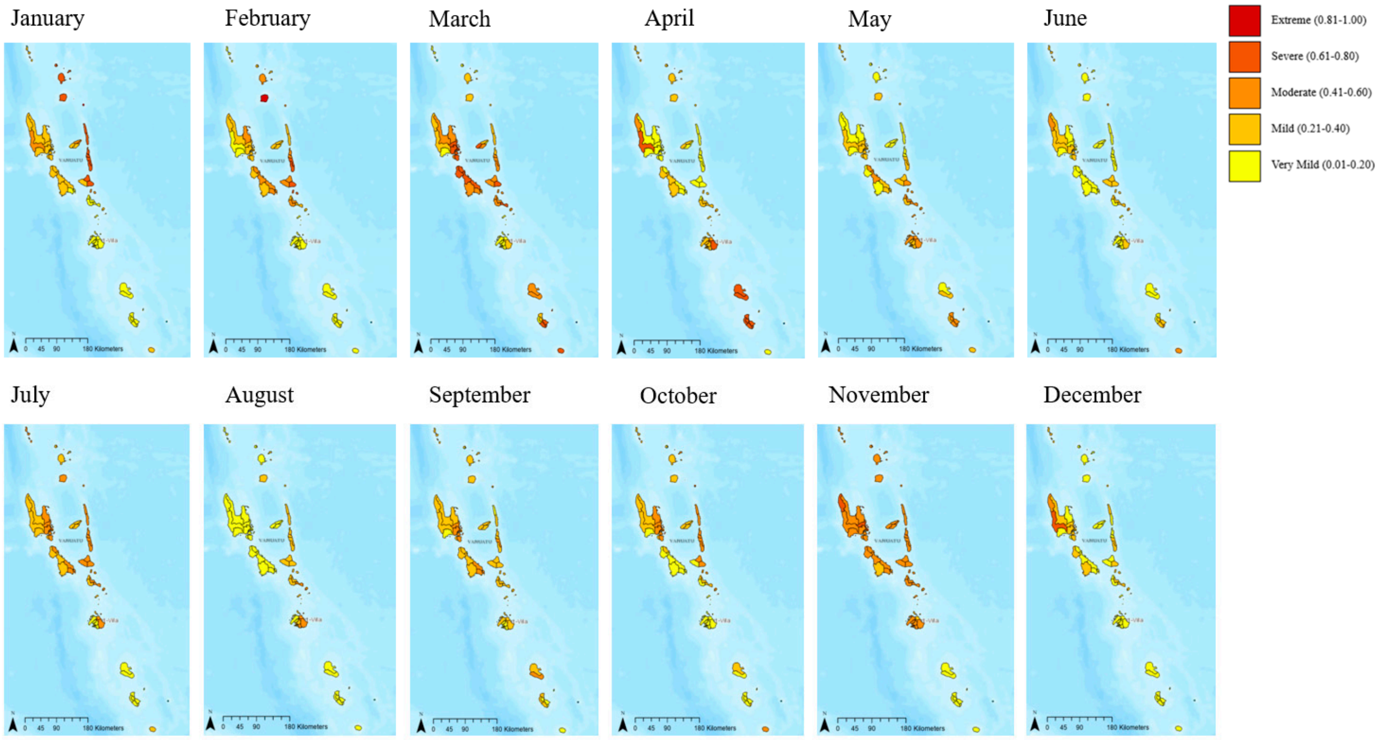


Figure 4. Comparison of monthly hazard index maps for Vanuatu area councils in 2015.

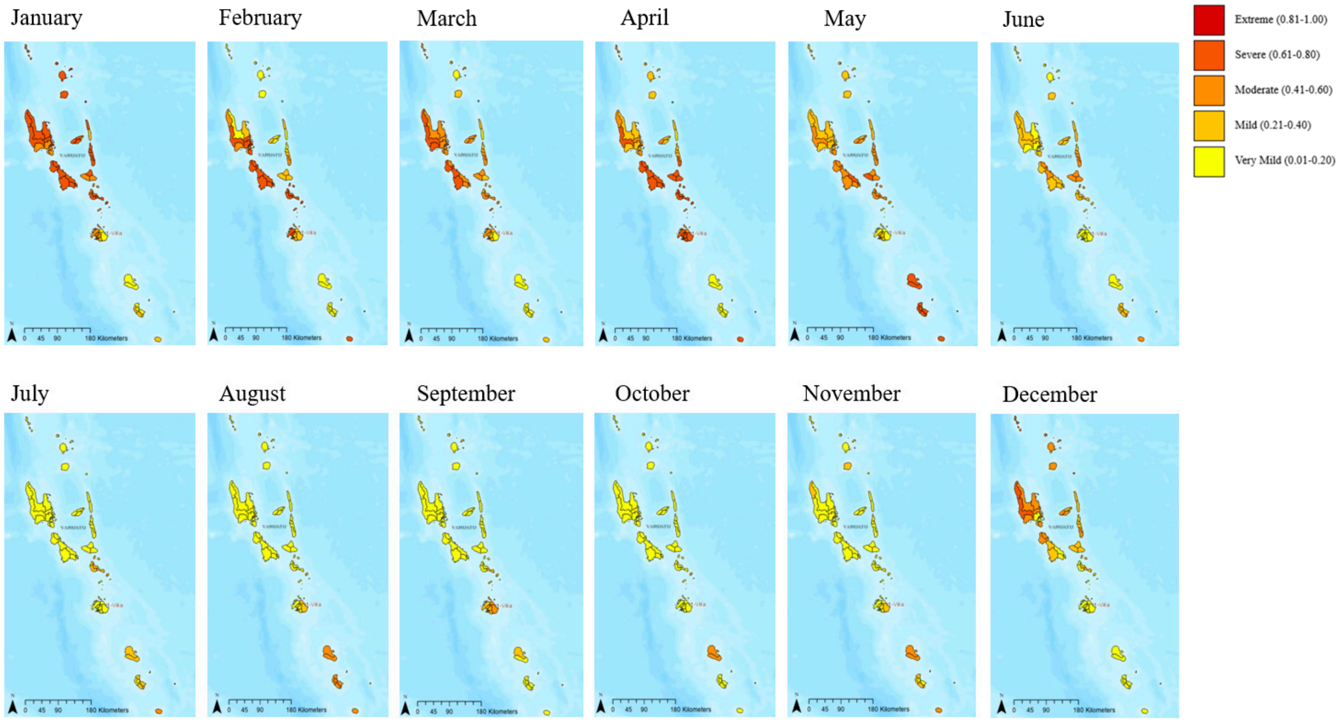


Figure 5. Comparison of monthly hazard index maps for Vanuatu area councils in 2016.

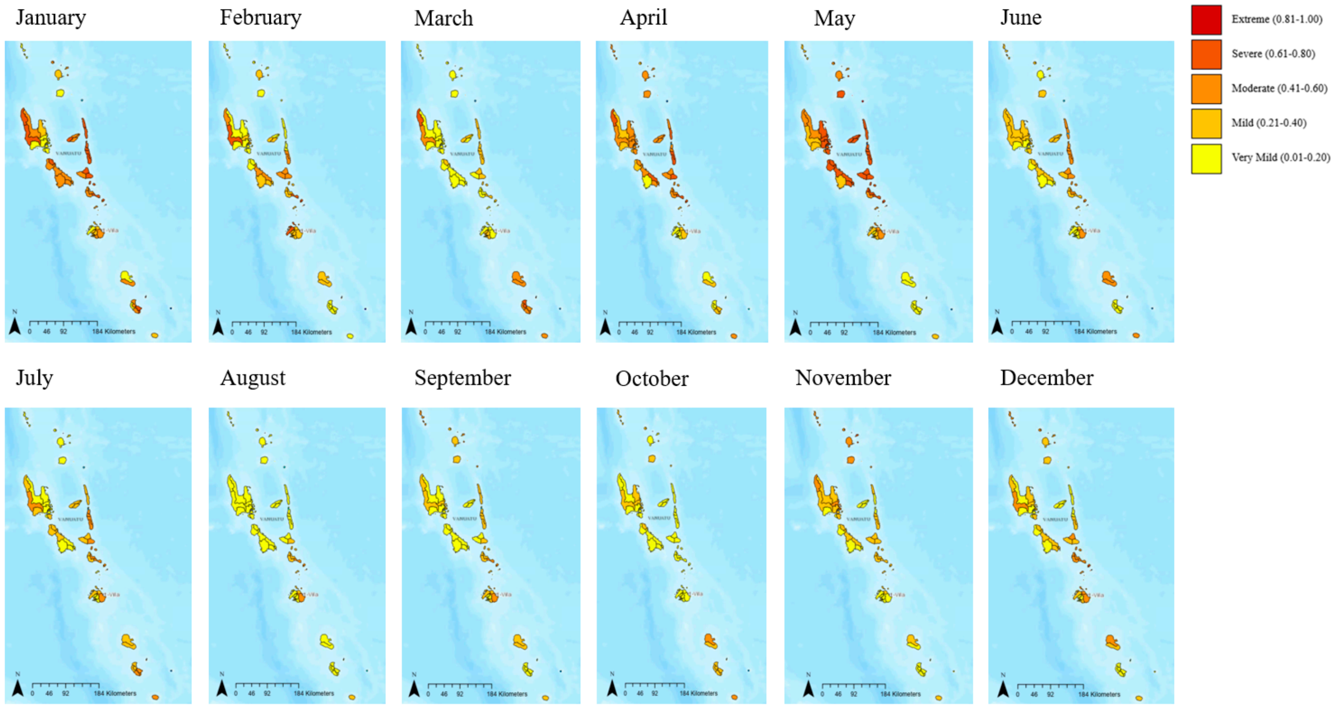


Figure 6. Comparison of monthly hazard index maps for Vanuatu area councils in 2017.

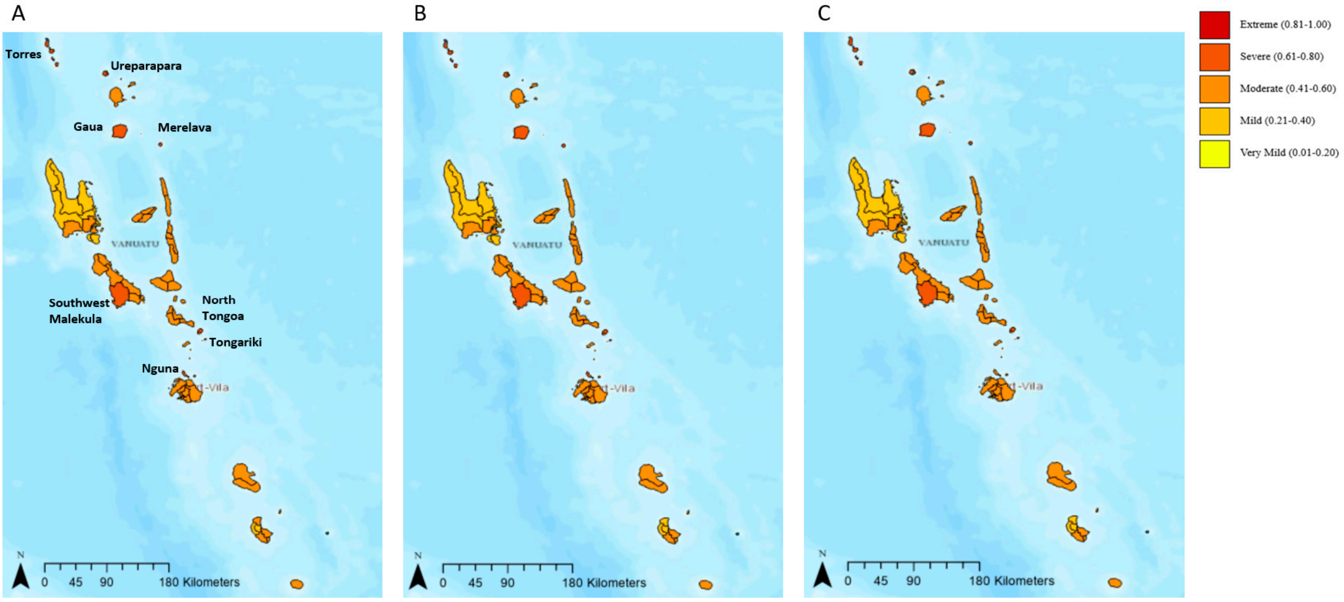


Figure 7. Comparison of yearly vulnerability index maps for Vanuatu area councils in 2015 (**A**), 2016 (**B**), and 2017 (**C**). Local area councils at high (severe or extreme) vulnerability levels are labelled.

3.1.2. Combined Risk

The risk assessment highlighted several periods of concern, with high MHW risk, throughout 2015–2017: January to March 2015, May 2015, July 2015, October to November 2015, January to May 2016, December 2016 to February 2017, April to May 2017, and November 2017. In these periods, MHW risk levels were seen to spike across the area councils throughout Vanuatu.

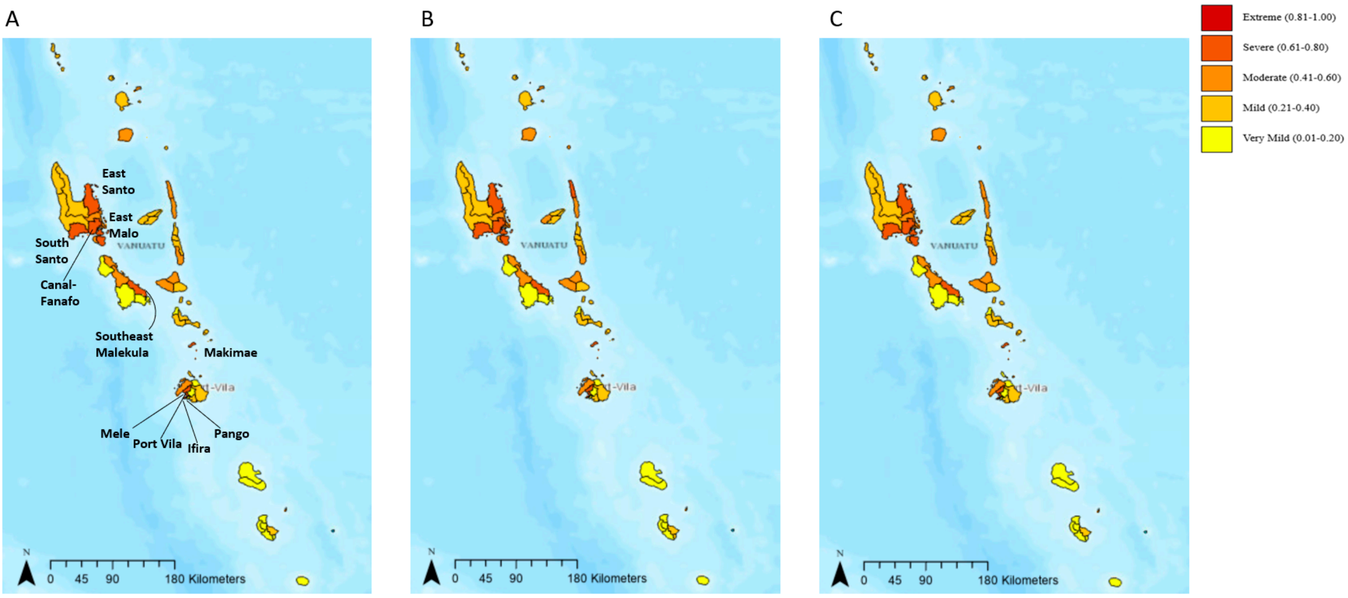


Figure 8. Comparison of yearly exposure index maps for Vanuatu area councils in 2015 (**A**), 2016 (**B**), and 2017 (**C**). Local area councils at high (severe or extreme) exposure levels are labelled.

In the first period of concern (January–Mar 2015), two area councils, Gaua and South Pentecost, were the most-at-risk (Table A2). Both areas of Gaua and South Pentecost were at risk of severe impacts throughout January and February and then moderate impacts in March. Other area councils of concern in this peak period were Canal-Fanafo, Central Malekula, Northeast Malekula, and Southeast Malekula, which had moderate risk levels in January–February which were then elevated to the risk of severe impacts in March. Merelava, North Ambrym, North Maewo, and South Maewo were also of concern, with severe levels at the beginning of the peak period (January) and then moderate levels for the rest of the period (Table A2). Motalava also had severe levels at the beginning of this period of concern; these levels then declined rapidly, changing to moderate in February and then mild in March. In May 2015, most area councils were at moderate risk levels, with Makimae displayed as having a risk of severe MHW impacts. In July 2015, the majority of area councils were at risk of moderate MHW impacts. Gaua was the most concerning in this period, with severe risk. Throughout the October–November 2015 period of concern, South Maewo was the most concerning area council with consistent severe risk levels. Canal-Fanafo, Gaua, and Makimae were also highlighted in the risk assessment as area councils of concern in this period, with moderate levels in October and elevated to severe levels in November (Table A2).

Overall, throughout the 2015 year, there were three neutral periods in which most area councils had mild or very mild levels in April and June, August to September, and December. Out of the 26 area councils that were at high risk (moderate or severe) at the beginning of the period of concern from October to November 2015, in the neutral period of August to September:

- 11 area councils expressed steadily increasing risk levels.
- One area council (North Maewo) expressed steadily decreasing levels prior to the period of concern in October-November (decreasing from moderate in August to mild in September) and then experienced a sudden spike back up to moderate risk at the beginning of the October–November peak period.
- 14 area councils expressed consistent risk levels, with no change throughout the two months of the neutral period. 11 of these expressed moderate risk throughout the neutral period, which continued throughout the peak period. Two area councils (North Pentecost and Torres) consistently had mild risk levels in the neutral period of August–September but then spiked to moderate levels at the beginning of the October–November

period of concern. 1 province (South Maewo) had consistently moderate levels in the neutral period of August–September, but levels jumped to severe risk at the beginning of the period.

The first period of concern (January–May 2016) arose, with most provinces expressing a moderate or severe risk level, with January 2016 being the most intense month out of the five months of this peak period (Table A3). Central Malekula, Makimae, and Southeast Malekula were the most at-risk area councils during the peak of January–May 2016, with a consistent risk of severe impacts. North Tongoa, Pango, and Tongariki were also of concern, with three out of the four months in the period of concern being severe risk for these area councils (Table A3). Other provinces of concern, with at least one or two months in the peak period being at severe risk levels, included Canal-Fanafo, Emau, North Ambryn, North East Malekula, North Maewo, South Pentecot, South Santo, West Ambrym, Ifira, Mele, and Port Vila. In December 2016 (which was the beginning of a signalled period of concern that endured until February 2017), the most common risk level throughout Vanuatu area councils was moderate. Gaua and Merelava were of high concern in this period, with severe risk levels (Table A3).

Overall, throughout the 2016 year, there was one neutral period from June to November in which most area councils throughout Vanuatu had very mild or mild risk levels (Table A3). Several area councils demonstrated a consistent transition from high MHW risk to impacts in the first period of concern, which ended in May 2016, until the second period of concern, which began in December 2016. Central Malekula, Central Pentecost 2, East Malo, Gaua, North Ambrym, North East Malekula, Paama, South Ambae, Southeast Ambrym, South Santo, Torres, Ureparapara, West Ambae, West Ambrym, and West Malo all demonstrated a decrease from higher risk levels (moderate or severe) in May 2016 to lower risk levels (mild or very mild), with most reaching their lowest risk value in August 2016, and then experienced a steady rise back up towards the higher risk levels (moderate or severe) demonstrated again in December 2016 (Table A3).

In the first period of concern during 2017, which continued from 2016 (December 2016–February 2017), Makimae, North Ambryn, and Tongariki displayed the highest risk levels (moderate/severe) (Table A4). Motalava, North Maewo, South Maewo, Gaua, and Merelava were also of concern, reaching severe risk in one month throughout this first peak period but changing rapidly to mild or very mild in the other months within the period. Gaua, Merelava, and South Maewo were also of high concern for the second period of concern (April–May 2017), with severe risk levels displayed for both months. Several months also displayed severe risk in this period, but only in one month (Central Malekula, Makimae, Motalava, North Ambrym, Northeast Malekula, North Maewo, Southeast Malekula, Tongariki, and West Ambrym). Gaua and Motalava were also of high concern in the period of concern that occurred at the end of 2017 in November, with a risk of severe impacts being displayed in the risk assessment (Table A4).

Overall, throughout the 2017 year, there were three neutral periods in which most area councils had mild or very mild levels (in March, in June–October, and in December). Following the first period of concern for the year, most previously high-risk area councils declined to moderate or mild risk levels in March (Table A4). A consistent transition out of and into MHW impacts was demonstrated throughout the second neutral period, which saw many provinces decline in risk following the period of concern in April–May, and then rise again into the peak in November. 14 area councils (Canal-Fanafo, Central Malekuls, East Malo, East Santo, Gaua, Makimae, Merelava, Mota, North Ambrym, Southeast Malekula, Southeast Santo, Tongariki, Torres, and West Ambrym) reflected a transition from high risk levels in May to mild and very mild levels throughout June-October, with levels slowly rising to high risk again in November (Table A4).

In comparing risk levels between case study years, higher risk levels were seen more commonly throughout Vanuatu during 2015 compared to 2016 and 2017, with 7 months of the year showing at least 1 local area council with a high-risk level (Figure 9). In all three years, high risk levels were evident during January, February, and May. In January 2016 and February 2016, a greater number of local area councils were at high risk compared to January and February 2015 and 2017 (Figure 9). May 2017 had a greater number of local area councils at high risk compared to May 2015 and 2016 (Figure 9).

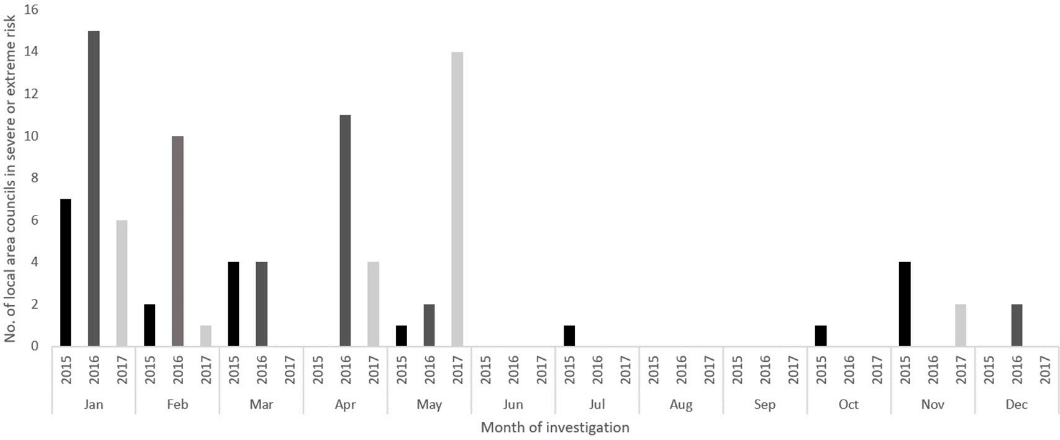


Figure 9. Comparison of monthly high-risk levels throughout each year of 2015–2017. The number of local area councils that expressed high risk (severe to extreme) is displayed for each year (2015 is represented by black bars, 2016 is represented by dark grey bars, and 2017 is represented by light grey bars) from January to December.

3.2. 2020–2022 Case Study Results

3.2.1. Hazard, Vulnerability, and Exposure

In each year of 2020, 2021, and 2022, hazard levels fluctuated greatly from month to month. In all years when hazard levels peaked throughout the country, levels tended to be greater in the central regions (Figures 10–12). However, there were some instances in peak hazard months where southern regions displayed greater hazard levels (e.g., December 2022) (Figure 12). In all three years, peak hazard levels were noticed in December. Other months of concern differed from year to year. For example, in 2020, January showed more neutral hazard levels (with most areas showing very mild, mild, and moderate levels), whereas in 2021 and 2022, January showed peak hazard levels (with most areas showing moderate and severe levels) (Figures 10–12). Overall, 2022 was the highest hazard year, with a greater number of months at peak hazard levels (with various local area councils at severe levels) compared to 2020 and 2021.

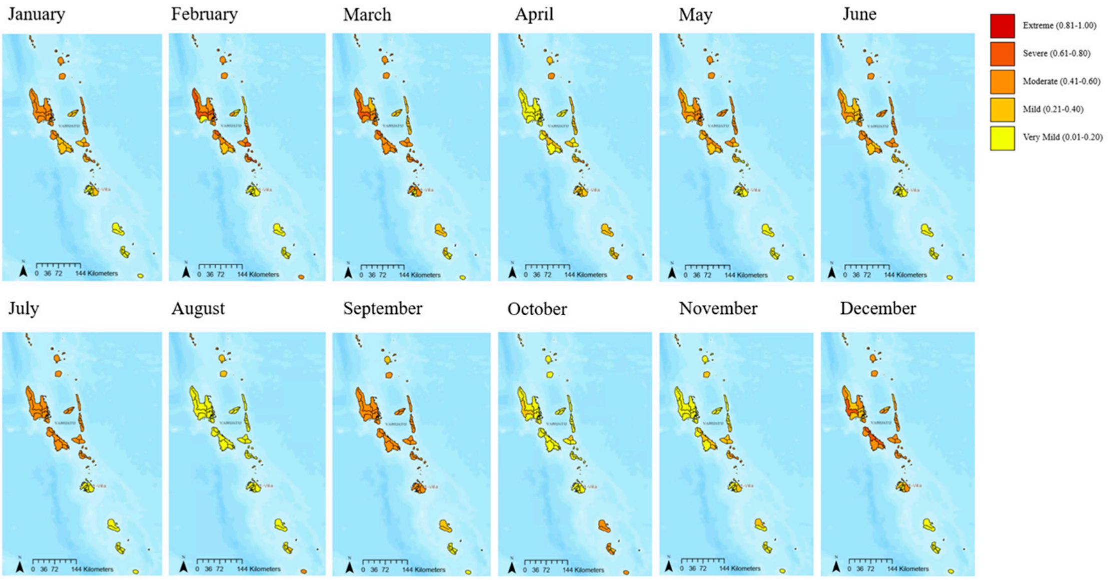


Figure 10. Comparison of monthly hazard index maps for Vanuatu area councils in 2020.

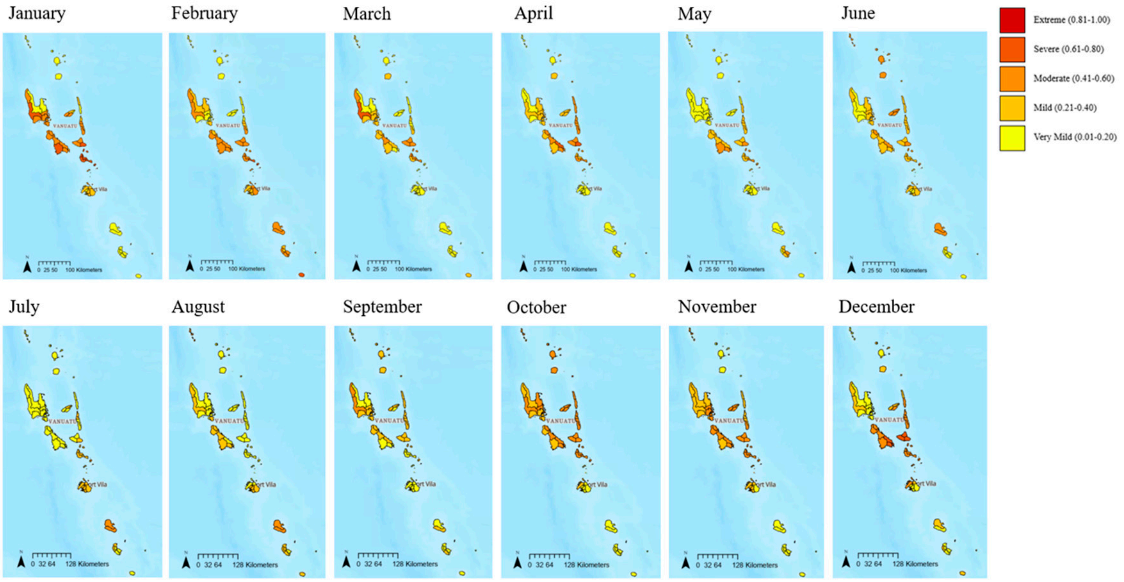


Figure 11. Comparison of monthly hazard index maps for Vanuatu area councils in 2021.

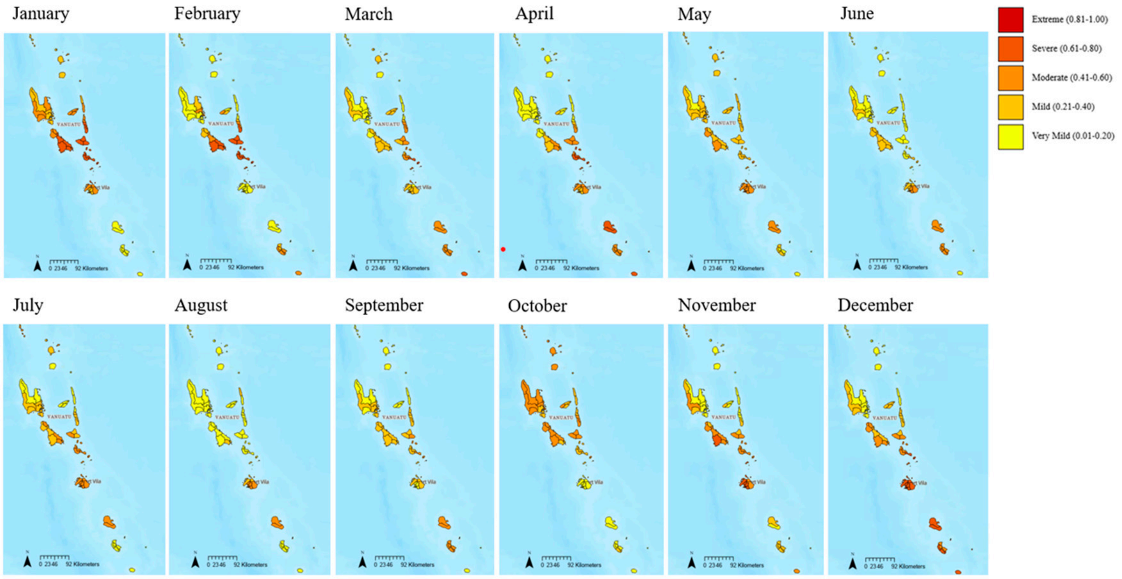


Figure 12. Comparison of monthly hazard index maps for Vanuatu area councils in 2022.

The most vulnerable area councils throughout Vanuatu included Nguna, Port Vila, Vanua Lava, and Motalava. These are spread across two provinces: Torba in the north (Vanua Lava and Motalava) and Shefa in central Vanuatu (Nguna and Port Vila) (Figure 13). More area councils were at severe levels of exposure compared to vulnerability. East Santo, East Malo, Canal-Fanafo, South Santo, Southeast Malekula, Makimae, Port Vila, Pango, and Ifira (Figure 13). Similar to vulnerability, the highest exposure levels were seen in Shefa province. However, area councils in Sanma and Malampa provinces were also seen with severe exposure (Figure 14). All area councils had at least mild levels of vulnerability and exposure, and no area councils had extreme levels. The vulnerability and exposure levels across all local area councils remained unchanged throughout the three-year period of 2020–2022.

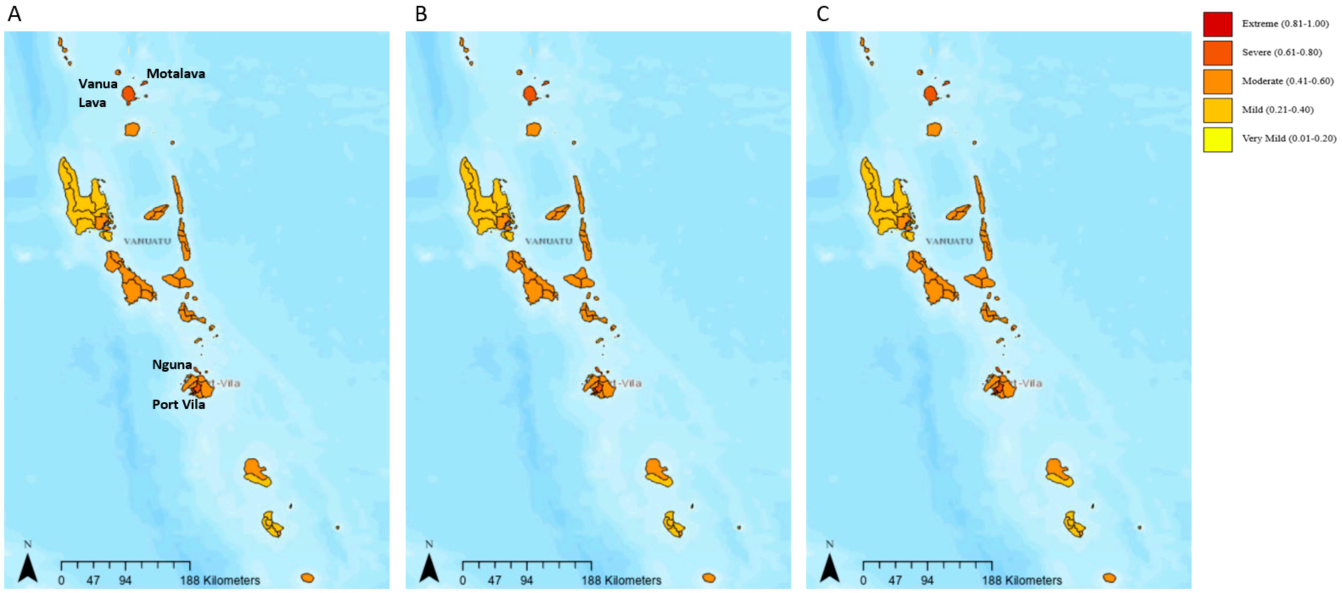


Figure 13. Comparison of yearly vulnerability index maps for Vanuatu area councils in 2020 (**A**), 2021 (**B**), and 2022 (**C**). Local area councils at high (severe or extreme) vulnerability levels are labelled.

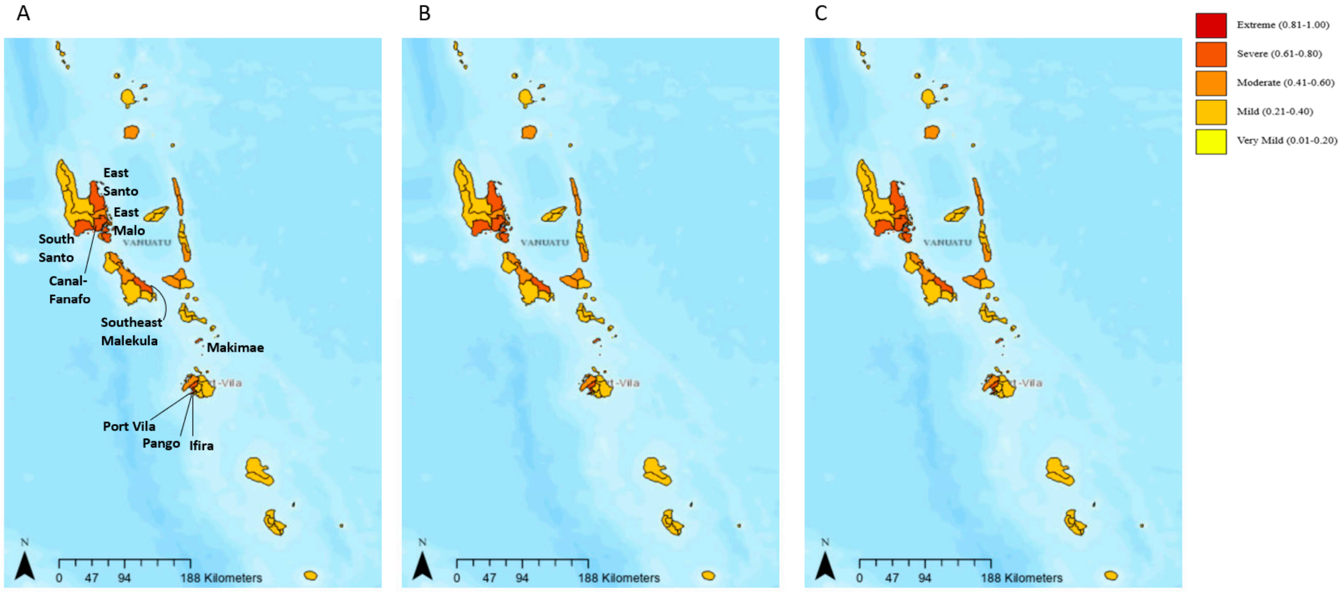


Figure 14. Comparison of yearly exposure index maps for Vanuatu area councils in 2020 (**A**), 2021 (**B**), and 2022 (**C**). Local area councils at high (severe or extreme) exposure levels are labelled.

3.2.2. Combined Risk

The risk assessment highlighted several periods of concern throughout 2020–2022: January to July 2020, September 2020, December 2020 to February 2021, November 2021 to August 2022, and November to December 2022. Most periods of concern in the 2020–2022 period lasted for a span of at least 3 months, with some extending to 10 months. These are much longer than the periods of concern observed throughout 2015–2017.

In the first period of concern in January to July 2020, the most at-risk area councils were Canal-Fanafo, Makimae, Motalava, and Port Vila (Table A5). Canal-Fanafo, Makimae, and Motalava were consistently at moderate and severe risk throughout this peak period. Whereas Port Vila expressed severe risk in April, then dropped throughout May and became low-risk in June with a very mild level. In September 2020, most area councils were at risk of moderate MHW impacts. Canal-Fanfo, Makimae, and Port Vila were the only area councils to display a higher risk level of severe in this month (Table A5). Only two neutral periods were observed in the 2020 risk assessment results: August 2020 and October to November 2020. In August, most area councils displayed a very mild risk level. In October, all area councils were of very mild or mild risk except for Mota and Motalava, which were at moderate risk. Levels then jumped in November, with 14 area councils displaying moderate risk (Table A5).

Throughout December 2020 to February 2021, Makimae was the most consistently at-risk area council, displaying a severe risk level in each of the three months in this period of concern (Table A6). Southeast Malekula was at risk of severe impacts in December 2020 but dropped to a moderate level of risk in January and February 2021. Canal-Fanafo rose from a moderate risk level in December 2020 to a severe level in January 2021 and then dropped back down to moderate in February 2021 (Table A6). A long neutral period was seen in 2021, from March to October, in which several transitioning patterns arose:

- Some area councils (Ifira, Makimae, Paama, Pango, Port Vila, Southeast Ambrym, Southeast Malekula, South Epi, South Pentecost, South West Malekula, Vermail, Varisu, Vermaul, West Ambrym, and West Malo) displayed a steadily decreasing pattern from the end of the period of concern in January/February 2021 to a specific low point in the neutral period, and then displayed a steady rise from that point to the start of the next peak period in November 2021.
- Some area councils (Erakor, Eton, and South Erromango) displayed steadily decreasing levels from the end of the January/February 2021 period of concern, reaching a low point in October 2021, with a sudden spike occurring to higher levels in November/December 2021, in which the next peak period commenced.
- All other area councils displayed a more random pattern throughout the neutral period, with rising and falling levels observed at many stages throughout March to October 2021.

Throughout the long period of concern from November 2021 to August 2022, the area council of Makimae was consistently at severe risk (Table A7). Southeast Malekula was at severe risk in the first few months of this peak period but dropped to moderate levels from March 2022 onwards. Mele, Pango, and Port Vila displayed moderate/mild risk levels throughout the first half of this period of concern, but levels escalated to severe and remained so throughout the remainder of the peak (Table A7).

Only one short neutral period was observed for 2022, from September to October (Table A7). In this neutral time, many of the moderately or severely at-risk area councils from the previous period of concern rapidly dropped to very mild/medium risk levels. This was particularly evident in area councils in or around Efate (Emau, Eratap, Eton, Ifira, Maloura, Mele, Pango, and Port Vila). Most area councils escalated rapidly from very mild or mild risk levels in the two months of this neutral period to returning to high risk levels in the November–December 2022 peak period. Particularly:

- Emau jumped from mild risk in October to moderate risk in November, and then spiked rapidly again to reach severe risk in December.
- Ifira rapidly escalated from a mild risk in October to a severe risk in November.
- Mele rapidly escalated from a very mild risk in October to a severe risk in November.
- Nguna jumped from very a mild risk in October to a moderate risk in November.
- Pango jumped from mild risk in October to severe risk in November.
- Port Vila rapidly escalated from a very mild risk in October to a severe in November.

Overall, the last period of concern in November to December 2022 was seemingly sudden, with no clear signal from the risk assessment of a transition into a period of high-risk MHW impacts.

In comparing risk levels between case study years, higher risk levels were seen more commonly throughout Vanuatu during 2022 compared to 2020 and 2021, with 10 months of the year showing at least 1 local area council with a severe risk level (Figure 15). In all three years, high risk levels were evident during January, February, and December. For

January and February, the number of area councils at high risk was similar between years. During December 2020 and 2021, two local area councils were at a severe risk level, but during December 2022, this escalated to six local area councils at severe risk (Figure 15).

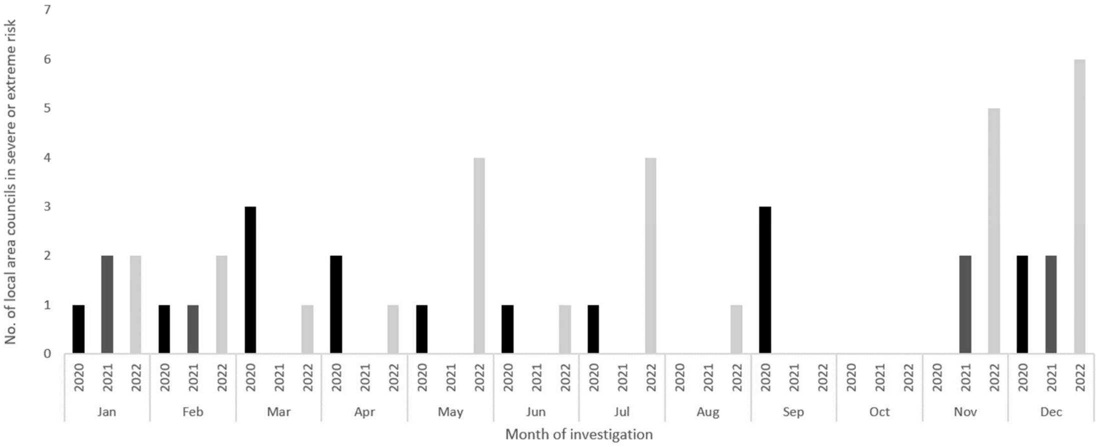


Figure 15. Comparison of monthly high-risk levels throughout each year of 2020–2022. The number of local area councils that expressed high risk (severe to extreme) is displayed for each year (2020 is represented by black bars, 2021 is represented by dark grey bars, and 2022 is represented by light grey bars) from January to December.

3.3. Sensitivity Analysis

The hazard index was strongly sensitive to SST in most of the tests performed. For area councils commonly at lower risk, in months of both high and low risk, the hazard index is seemingly highly sensitive to SST (Table 6). In area councils commonly at higher risk, the hazard index was strongly sensitive to SST in months of high risk but was not as sensitive to this indicator in higher risk months (with an SI decreasing from 0.90 in lower risk months to 0.59 in higher risk months). In area councils of commonly higher risk, during lower risk months, all three hazard indicators displayed high SI's, indicating that the hazard index is likely strongly sensitive to changes in each indicator during these periods (Table 6). Slight increases in sensitivity were detected for BAA and Chlorophyll-a concentrations in area councils of commonly lower risk during lower risk months compared to higher risk months (increasing from 0.36 to 0.56 and from 0.27 to 0.47, respectively). Despite increases, sensitivity to each of these indicators remained relatively weak.

Table 6. Sensitivity of the hazard index to the different hazard indicators used in this study. The Sensitivity Index (SI) for each indicator is provided for all example tests conducted.

Local Area Council Type	Hazard Indicator	SI in Higher Risk Months (Represented in Testing with April 2022 Data)	SI in Lower Risk Months (Represented in Testing with September 2021 Data)
Makimae (representing local area councils commonly at higher risk)	SST	0.59	0.90
	BAA	0.35	0.83
	Chlorophyll-a concentration	0.2	0.80
West Tanna (representing local area councils commonly at lower risk)	SST	0.86	0.90
	BAA	0.36	0.56
	Chlorophyll-a concentration	0.27	0.47

The vulnerability displayed no strong sensitivity to any of its indicators. The SI for the different vulnerability indicators did not greatly differ across area councils of high versus low concern, or across years of high versus low concern (Table 7). Sensitivity was slightly higher for all vulnerability indicators in West Tanna (representing low-risk area councils) compared to Makimae (representing high-risk area councils), but this difference was minimal. When considering the SI of indicators in high-risk years compared to low-risk years, very minimal differences were seen (with 0.01 beginning the maximum difference).

Table 7. Sensitivity of the vulnerability index to the different vulnerability indicators used in this study. The Sensitivity Index (SI) for each indicator is provided for all example tests conducted.

Local Area Council Type	Vulnerability Indicator	Sensitivity Index in Higher Risk Years (Represented in Testing with 2016 Data)	Sensitivity Index in Lower Risk Years (Represented in Testing with 2021 Data)
Makimae (representing local area councils commonly at higher risk)	Terrestrial-based food and income generation	0.41	0.42
	Fishing skills and technology	0.16	0.16
	Fishery diversity/flexibility	0.42	0.43
	Primary production of commercial fisheries	0.34	0.35
West Tanna (representing local area councils commonly at lower risk)	Terrestrial-based food and income generation	0.53	0.53
	Fishing skills and technology	0.19	0.18
	Fishery diversity/flexibility	0.51	0.52
	Primary production of commercial fisheries	0.39	0.40

High sensitivity was detected in the exposure index when tested against the seagrass population data for area councils commonly at low risk during both high-risk and low-risk years (Table 8). All other indicators displayed much lower SI values in all sensitivity tests. Sensitivity to all indicators was much higher for the West Tanna indicator data compared to Makimae in both high and low risk years, but in all cases except seagrass populations, SIs did not reach the strong sensitivity classification. SI values were very similar for each indicator when comparing across higher-risk years and lower-risk years (Table 8).

Table 8. Sensitivity of the exposure index to the different exposure indicators used in this study. The Sensitivity Index (SI) for each indicator is provided for all example tests conducted.

Local Area Council Type	Exposure Indicator	Sensitivity Index in Higher Risk Years (Represented in Testing with 2016 Data)	Sensitivity Index in Lower Risk Years (Represented in Testing with 2021 Data)
Makimae (representing local area councils commonly at higher risk)	Seagrass population	0.41	0.42
	Crown of thorns prevalence	0.35	0.35
	Crab stock health	0.12	0.12
	Fish stock health	0.23	0.23
West Tanna (representing local area councils commonly at lower risk)	Seagrass population	0.80	0.81
	Crown of thorns prevalence	0.62	0.63
	Crab stock health	0.41	0.41
	Fish stock health	0.64	0.65

4. Discussion

4.1. Time Periods of Concern, as Indicated by the Risk Assessment

The years and months of concern that are highlighted by the risk assessment reflect the various climate drivers and influences of marine heat wave events, known to influence conditions across the Pacific, as well as the various factors of vulnerability and exposure evident across Vanuatu. The risk assessment highlighted several periods of concern, with elevated MHW risk, throughout 2015–2017: January to March 2015, May 2015, July 2015, October to November 2015, January to May 2016, December 2016 to February 2017, April to May 2017, and November 2017. The risk assessment also highlighted several periods of concern throughout 2020–2022: January to July 2020, September 2020, December 2020 to February 2021, November 2021 to August 2022, and November to December 2022. The regular occurrence of short peaks in risk throughout the case study years is not unexpected. In the Southwest Pacific, MHW events are known to occur at a high frequency, adding to the cumulative stress exerted on local communities each year [40]. Overall, these periods of concern, signifying heightened risk of significant MHW impacts, align with the years and months we expect impactful MHW events to have occurred in the past due to the climatic factors that drive MHW conditions.

The timing of MHW events and impacts in South Pacific SIDS can be somewhat linked to the different phases of ENSO and the occurrence of TCs. Historically, throughout MHW, conditions have been noted to be associated with the La Nina ENSO phase [41]. Vanuatu is described by Sen Gupta et al. [3] as typically associated with warming during La Niña events (being a part of the south-western subtropical Pacific), often experiencing its most severe MHW during La Niña periods. However, recent evidence displays that strong MHWs can also occur in the absence of these climatic periods, rather than resulting from long-term climate change and local drivers [42]. Additionally, climatic factors only relating to SST increase information on just one area of hazardous MHW conditions. There are many other systems and factors with feedback that facilitate MHW intensification (e.g., wind-evaporation-SST feedback) [3].

The South Pacific convergence zone (SPCZ) is a climate system progressively noted as an influencer of MHW conditions across countries such as Vanuatu, which may itself be varied in response to ENSO and the IPO [41]. The SPCZ stretches across the southwest Pacific Ocean, covering Pacific SIDS such as the Cook Islands, Fiji, Nauru, Niue, Samoa, Solomon Islands, Tonga, Tuvalu, Vanuatu, and Kiribati [43]. Gouriou and Delcriox [41] define the SPCZ as a "diagonal band of intense rainfall and deep atmospheric convection extending from the equator to the subtropical South Pacific". When the SPCZ is displaced, variation is seen in rainfall, marine heat wave conditions, tropical cyclone activity, etc. This subsequently impacts the ecosystems and communities in countries such as Vanuatu [41]. From November to April, the SPCZ is more active, coinciding with the summer season in Vanuatu (November to March).

MHWs have also occurred commonly at the same time as more extreme tropical cyclone events, with evidence of the strengthening of TCs due to the presence of MHWs [44]. This is due to the influence of SSTs on the development of TCs, which draw energy from warming ocean waters to develop and intensify [45]. Lavender et al. [45] demonstrated that in the Pacific, an increase in SSTs can result in heightened intensity, precipitation, and integrated kinetic energy from storms resultant of TCs. However, there was no influence on TC tracks prior to landfall. Overall, it is expected that the occurrence of a MHW and an intense TC at the same time in a country namely Vanuatu would have interlinking, damaging impacts on the environment and communities.

The many peak periods displayed from 2015 and 2016 by the risk assessment are expected, with a 2015–2016 El Nino noted as causing MHW conditions in Pacific islands such as Vanuatu, with its warming signature concentrating in Fiji and surrounding countries [40]. Notably, the March 2015 severe MHW risk levels are congruent with impacts caused by Tropical Cyclone (TC) Pam, which occurred across Vanuatu in mid-March 2015 as an intense Category 5 event. At this time, several adverse impacts on Vanuatu fisheries occurred due to the TC, which likely increased vulnerability to other disaster events, including MHWs in local Vanuatu communities [46]. Terrestrial-based food and income generation were significantly reduced following TC Pam, with shortages in drinking water, crops, and infrastructural damages occurring. This caused increased reliance on marine resources to support communities. However, fishing skills and technology were low, and this reduced the ability of marine resources to support recovery in local communities [5]. The periods of concern displayed by the risk assessment for the beginning of 2017 (February, April and May) are likely concurrent with impacts induced by Category 4 TC Donna. TC Donna occurred at the beginning of May 2017, disrupting Vanuatu marine ecosystems via algal blooms [47].

The high-risk levels indicated by the risk assessment in the periods of concern throughout 2020, 2021, and 2022 could be signalling impacts associated with the extended La Nina period that occurred in 2020, 2021, and again in 2022. In this three year La Nina period, an increase in the strength and intensity of trade winds was seen, which enhanced the warm pool in the Western Pacific [22]. As a result, countries such as Vanuatu experienced warming ocean temperatures and heightened coral bleaching. Notably, February 2021 saw the occurrence of four TC events (TC Lucas from January 29 to February 4, TC Bina from January 29 to February 1, TC Ana from January 28 to February 3, and TC Niran from February 27 to Mar 7) [48].

The longest MHW-impact peak periods, indicated by the risk assessment, were seen in 2016 (with a 5-month peak from January–May), 2020 (with a 7-month peak from January–Jul), and 2022 (with 8 months in 2022 extending the peak that was noted to begin in November-December in 2021). 2022 also displayed the most months in which significant MHW impacts were likely to occur, with the risk assessment recording 10 peak months spread throughout this year. It is not unusual that the risk assessment identified increasingly long periods of high-risk MHW impacts. MHW events are progressively extending, with recent MHWs known to endure for over 250 days [3]. The long period of concern in 2016 most likely signalled the impact period for the 2015–2016 El Nino-induced MHW event in the Pacific [3]. The extended period of concern in 2020 could have been signalling the risk of impacts to fisheries from MHW conditions concurrent with the intensification of severe TC Harold, which was widely destructive across Vanuatu throughout April 2020 [49]. Additionally, throughout 2020, Vanuatu was recorded to have been undergoing an extended mass coral bleaching event [42]. 2022 is expected to be a year in which Vanuatu fisheries experience many MHW-induced impacts. The occurrence of Category 4 TC Dovi in February 2022, as well as a mass coral bleaching event that persisted throughout the year, means it was expected to see some high-risk signals throughout 2022 in the risk assessment results [42].

4.2. Areas of Concern as Indicated by the Risk Assessment

Throughout the periods of concern highlighted by the risk assessment, MHW risk levels were seen to spike across the area councils throughout Vanuatu, but there were area councils signalled as distinctly more at-risk than others during each peak. The local area councils of concern that are highlighted by the risk assessment reflect the proximity to MHW hotspots (the Pacific Warm Pool and the South Pacific Convergence Zone), which elevate hazardous conditions, as well as the various factors of vulnerability and exposure evident across Vanuatu.

At the beginning of the first period of concern (January–March 2015), higher risk levels were seen across area councils in the Northern and Central regions of Vanuatu (in Torba, Penama, and Malampa provinces). Most of these severely at-risk provinces dropped to moderate levels in February 2015, with only Gaua and South Pentecost area councils persisting at severe risk levels. Gaua is expected to have such high-risk levels in times of increased hazard, as it is severely vulnerable and moderately exposed to MHW fisheries impacts. The South Pentecost risk levels were most likely a result of high hazard levels in combination with moderate-severe exposure levels for 2015. At the end of this period, in March 2015, higher risk levels were seen in Sanma and Malampa provinces. Impacts that would have likely occurred in the high-risk area councils during this period include significant fish die-offs, significant deaths of other marine animals, coral bleaching, increased prevalence of crown of thorns, algal blooms, reduced catch amounts, and reduced productivity of commercial fisheries. Eriksson et al. [5] explain that communities throughout Malampa and Shefa provinces noted a crow-of-thorns outbreak in March 2015, which caused coral mortality. Shefa and Sanma provinces were noted as having reduced fisheries resilience at this time due to the impacts of TC pam; the risk of experiencing severe MHW impacts in these provinces would be increased [5].

In the longer period of concern from January to May 2016, severe impacts were seemingly widespread, affecting area councils throughout all provinces of Vanuatu at some point. Overall, Southeast Malekula was the most concerning area council for this peak period, with persisting severe risk levels for each of the five months. This is not unexpected, as Southeast Malekula is severely exposed to MHW impacts, with moderate vulnerability. Particularly low biodiversity in Southeast Malekula's seagrass habitats and poor crab stock levels result in high exposure levels, making it more at risk to not only the environmental impacts of MHWs but to fisheries production and income generation as well (as these socio-economic factors heavily rely on the health of marine ecosystems in Vanuatu) [30]. Central Malekula, Makimae, and North Tongoa were also of high concern, with severe risk levels displayed in these area councils for four out of the five months in this period. Unexpectedly, Aniwa displayed severe risk levels in the last month of this period. Throughout all periods of concern, area councils in Tafea province were not commonly displayed as having high risk levels. This may be because of the southern location of Aniwa and the other area councils in Tafea province. The southern areas of Vanuatu are less likely to experience warming waters associated with the Indo-Pacific Warm Pool [50].

During peaking MHW risk in December 2016 to February 2017, high risk levels were seen in the northern province of Torba and the central provinces of Penama, Malampa, and Shefa. Impacts were seen across several area councils in both December 2016 and January 2017 but were focused only in Tongariki throughout February 2017. Tongariki is expected to have a high risk of MHW impacts when hazard conditions elevate, as it is a highly exposed area. Exposure levels across Tongariki are elevated due to minimal crab stock levels and low fish stock levels. Crab and fish species underpin the fisheries industry in Vanuatu [4,51]. Both crabs and fish species can be harshly affected by MHW events, with MHW impacts known to result in mortality, species range shifts, and reductions in recruitment [4]. Throughout the period of concern in April–May 2017, we saw severe risk levels persisting for Canal-Fanafo, South Maewo, and Merelava. These span across three different provinces (Sanma, Penama, and Torba, respectively). This is interesting, as it gives evidence of widespread impact across the entire country of Vanuatu rather than localised impacts in one specific province.

In the seven-month period of concern from January–July 2020, severe impacts were likely widespread across Vanuatu, with high risk levels displayed for Torba, Sanma, and Shefa provinces. The two most concerning area councils in this period included Canal-Fanafo of Sanma province, which had severe risk levels persisting across three months in this period, and Motalava of Torba province, which had severe risk levels persisting for four months in this period. Throughout the period of concern from December 2020 to February 2021, Makimae area council displayed severe risk for each month. Makimae is expected to have high risk levels, even in periods of lower hazard levels. This is because it has moderate, vulnerable, and severe exposure levels. Particularly, Makimae has extremely low species richness for its seagrass population. Seagrass ecosystems are critical in Vanuatu, supporting biodiversity in various ways. Particularly, seagrass ecosystems in Vanuatu provide a primary food source for the keystone species of dugongs and turtles and provide a nursery habitat for fish and invertebrates. In supplying such services, seagrass populations contribute both directly and indirectly to food security and the function of the fisheries industry in Vanuatu [48]. Seagrass populations are increasingly under threat from climate change impacts; when seagrass ecosystem health is reduced, severe negative impacts on fisheries can ensue when elevated MHW hazard conditions arise [52]. Impacts on fisheries would be further compounded in Makimae, as it has lower fishery diversity, with fisheries in this area council relying on a reduced number of species compared to other area councils [51].

For the long, ten-month peak period of November 2021 to August 2022, many area councils exhibited severe risk levels: Canal-Fanafo, Makimae, Southeast Malekula, Mele, Pango, and Port Vila. Most of these high-risk area councils are located in Shefa province (all but Canal-Fanafo and Southeast Malekula). Particularly, Canal-Fanafo and Southeast

Malekula are expected to have high risk levels in times of increased hazards, due to their severe exposure levels. Makimae was particularly concerning for this period, with severe levels shown for eight out of the ten months in this period of concern (it dropped to a moderate risk level in both June and August).

In the last period of concern indicated in this study by the risk assessment (November–December 2022), severe risk levels were localised to area councils in or around Efate Island. Efate Island area councils are moderately vulnerable to MHW fisheries-based impacts, but area councils such as Mele, Pango, Ifira, and Port Vila are severely exposed. Particularly, these area councils have a high prevalence of COTs, leaving their marine ecosystems highly exposed to MHW impacts. Dumas et al. [31] explain that COT outbreaks in Pacific SIDS such as Vanuatu raise concerns about environmental and economic dependence on coral reef ecosystems. The high prevalence of the coral-eating COT starfish (*Acanthaster planci*) causes coral mortality, decreased biodiversity in coral reef ecosystems, and overall reef degradation. Cascading effects include decreases in fish and invertebrate resources, as well as threatened food security and fisheries production [31]. Thus, when hazard conditions elevate, the highly exposed area councils on Efate Island are expected to rise to concerning risk levels.

4.3. Credibility of Risk Assessment Indicators

Despite slight changes in sensitivity evident across different types of area councils and different month/year types, most sensitivity detected for hazards, vulnerability, and exposure was weak, meaning most indicators remained robust throughout all tests. High sensitivity was only detected for the following: the hazard index to SST for higher risk months in commonly lower risk area councils; the hazard index to all three indicators (SST, BAA, and chlorophyll-a concentrations) in area councils commonly of high risk and those commonly of low risk during low-risk months; the exposure index to seagrass population in area councils commonly of lower risk in both high and low risk years

It is not unexpected that hazard index sensitivity be greater for SST than the other hazard indicators, as SST was assigned a greater weight in index calculations. However, the greater weight of SST would only account for sensitivity to SST being higher than the other indicators, not necessarily that sensitivity to SST be classified as strong. This suggests that SST may not be as ‘robust’ as the other indicators in the research. Accordingly, there is potential to revise the weighting scheme applied to each hazard indicator, with a recommendation to reduce the weight applied to SST, giving it a similar weight to that of BAA. Further expert advice should be sought on such revisions [53].

The high sensitivity detected across all three hazard indicators during low-risk months is not an unreasonable result. During such periods of low concern, any spike in indicator data (higher SSTs, greater BAA, or lower Chlorophyll-a concentrations) could mean a significantly increased hazard level and an ensuing increase in overall risk. Thus, this result is unlikely due to the decreased ‘robustness’ of hazard indicators, but rather to the nature of the risk assessment itself.

The high sensitivity of the exposure index to seagrass populations in low-risk area councils is not unreasonable. The seagrass population indicator is weighted the most among exposure indicators. Thus, in low-risk areas, if the seagrass population decreased, the overall exposure would likely greatly increase, and the overall risk would be greater. However, as in SST, the greater weight of the seagrass population does not necessarily warrant the high sensitivity level detected. It would be expected that sensitivity would be slightly greater in the seagrass population than in other exposure indicators but would not necessarily be at a high level. This suggests reduced ‘robustness’ of the seagrass population indicator compared to the other exposure indicators. As such, it is recommended that exposure indicator weighting be revised in the future, with the weight applied to the seagrass population potentially reduced. This revision should be based on expert advice [53].

4.4. Methodological Limitations and Advances

The two time periods chosen for investigation may seem static without guidance for the future. This study is intended to demonstrate the ability of the risk assessment methodology to signal risk to Vanuatu fisheries for the transition into and out of MHW events. The retrospective time periods were chosen for use as examples in which the ability of the MHW risk assessment methodology to have signalled MHW risk levels in the past could be demonstrated. The risk assessment is not recommended for operational use at this stage; this study is more focused on a test of methodology. Only once this methodology is comprehensively validated can it be recommended for use in the future in an operational sense. Thus, the investigation of the two retrospective time periods is deemed sufficient at this time for this study's aims. Although this assessment covered a large enough time period to demonstrate the ability of the risk assessment in picking up the signals of transitioning into and out of MHW events, it would be useful in the future to 'fill in the gaps' for the years between 2018 and 2019. There have been no significant MHW impacts recorded in these years, but it would be useful to determine if the risk assessment would pick up 'false positives' during these years and signal a MHW event when one did not actually occur. If the MHW risk assessment methodology developed here is to be implemented operationally in the future, the risk assessment should be conducted over a longer historical period to provide sufficient background for future monitoring.

Additionally, there were no extreme risk levels expressed in the retrospective risk assessment results, which may be a result of methodological limitations. For example, hazard levels could be underrepresented because of different lag times in the three hazard indicators. Where SST elevates, coral bleaching may lag in signalling high levels of hazard until a month after this, in response to raised SST levels. This may mean that high SST and coral bleaching levels would not converge in the same month to signal more extreme hazard levels and resultant extreme risk levels. However, the fact that no extreme events were signalled could be because no extreme MHW events have occurred in years of investigation. Although the impacts of such periods as 2016 saw intense MHW impacts in Vanuatu, the specific impacts that occurred only amounted to the category of severe (as described in the literature [24,54]). Thus, the risk assessment is likely still valid and suggests that it is not too sensitive to overestimate high-risk signals. The methodology should be tested in future MHW events, in which impacts reach the extreme category.

The selected MHW indicators and the weights assigned to each of them were validated through sensitivity analysis. However, the overall results of the risk assessment require further validation. There are several approaches commonly used to validate disaster risk assessment results (e.g., comparison against historical records, ground-truthing through local opinion, statistical analysis, etc.). However, each method has its associated downfalls [29]. Comprehensive validation of risk assessment results would use several of these techniques in combination to ensure reliability [29]. A comprehensive validation approach was beyond the scope of this paper, but future research will be dedicated to conducting this.

In this research, significant effort was made to address the key knowledge gaps widely omitted from MHW risk assessment studies globally, as well as in Vanuatu specifically [1]. In many past studies, aspects of effective risk assessment were commonly lacking: dynamically including hazard, vulnerability, and exposure indices; tailoring the selection and weightings of indicators; holistically incorporating both ecological and human indicators into risk indices; and calculating and producing risk indices and maps using integrated GIS-based techniques [55]. The MHW risk assessment methodology tested here incorporated each of these aspects and demonstrated the temporal and spatial transition of MHW risk levels for Vanuatu fisheries.

Specifically, introducing a sectoral focus for MHW risk assessment in Vanuat, is a novel approach to risk assessment in Pacific SIDS and increases the specificity of the risk assessment to inform action-based management decisions. Few studies have specifically focused on the MHW risk to Pacific SIDS fisheries [1]. It is important to develop specific risk indices for each of the key sectors in a vulnerable area. In doing so, index results can be increasingly informative and aid key sectoral decision-makers in preparing for and responding to an MHW event [56]. In a study region that has many major sectors that should be assessed, a risk index should be developed for each specific sector. In Vanuatu, fisheries are a key sector, along with agriculture and tourism. MHW impacts on fisheries have already been noted across the world, but they remain underexplored in Pacific SIDS such as Vanuatu [4]. This research has provided an initial exploration into MHW risk for fisheries in Vanuatu, demonstrating the potential of a MHW risk assessment tailored for Vanuatu fisheries to provide useful risk information and building a foundation for expanding MHW risk knowledge for fisheries in Vanuatu [4].

4.5. Implications for the Future

This work was produced in collaboration with the Vanuatu meteorological services, the Vanuatu fisheries department, and Vanuatu locals to ensure the user-centeredness and applicability of the risk assessment. It is intended that the risk assessment methodology demonstrated in this study will be applied in future scenarios by the meteorological services in Vanuatu and the Vanuatu fisheries department to indicate MHW risk levels on a localised scale throughout the country and inform resilient MHW risk management responses for the fisheries sector and local coastal communities (e.g., priority resources can be allocated to regions of higher risk). Currently, the incorporation of risk knowledge into fisheries management strategies in Vanuatu is minimal [8]. Before this risk assessment can be applied in the future and before specific management recommendations can be made from such a risk assessment, the results of this study must be further validated. Future research should focus on conducting a comprehensive validation of the MHW risk assessment accuracy in indicating risk levels throughout Vanuatu through a comparison of the MHW risk index results with multiple ground truth sources [29].

5. Conclusions

The MHW risk assessment methodology, specifically incorporating key methodological aspects for efficiency, was applied to the context of MHW risk assessment for fisheries in Vanuatu. The risk assessment successfully highlighted key areas and months of concern in terms of high-risk levels throughout each case study period. A particular period of concern was highlighted throughout January–May 2016 and again in January–July 2022. Significant MHW impacts were likely occurring at these times. Throughout 2016, local area councils spread throughout Shefa province, as well as areas on Malekula island. During 2022, Makimae, as well as local area councils on Efate Island, displayed concerning risk levels. These results could have implications for MHW risk management in Vanuatu fisheries; however, recommendations based on this research are limited until a more comprehensive validation can be performed. Overall, this research contributes to expanding MHW risk knowledge for the key sector of fisheries across Vanuatu and demonstrates the potential for the fisheries-specific MHW risk assessment to inform where and when MHW impacts are most likely to be felt. Next steps would include result validation through comparison with ground-truth sources and incorporation of the MHW risk assessment with fisheries risk management processes in Vanuatu.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. What-if analysis data table example- This example shows the data table produced when examining hazard index sensitivity to SST using Makimae data for the month of April 2022.

SST Indicator	Hazard Index
original	0.719
0.1	0.309
0.2	0.359
0.3	0.409
0.4	0.459
0.5	0.509
0.6	0.559
0.7	0.609
0.8	0.659
0.9	0.709
1	0.759

Appendix B

Table A2. Monthly risk index levels for Vanuatu area councils throughout the year of 2015. Risk index levels are categorised into five severity classes: Extreme (0.81–1.00) 🟥, Severe (0.61–0.80) 🟫, Moderate (0.41–0.60) 🟧, Mild (0.21–0.40) 🟨, and Very Mild (0.01–0.20) 🟡.

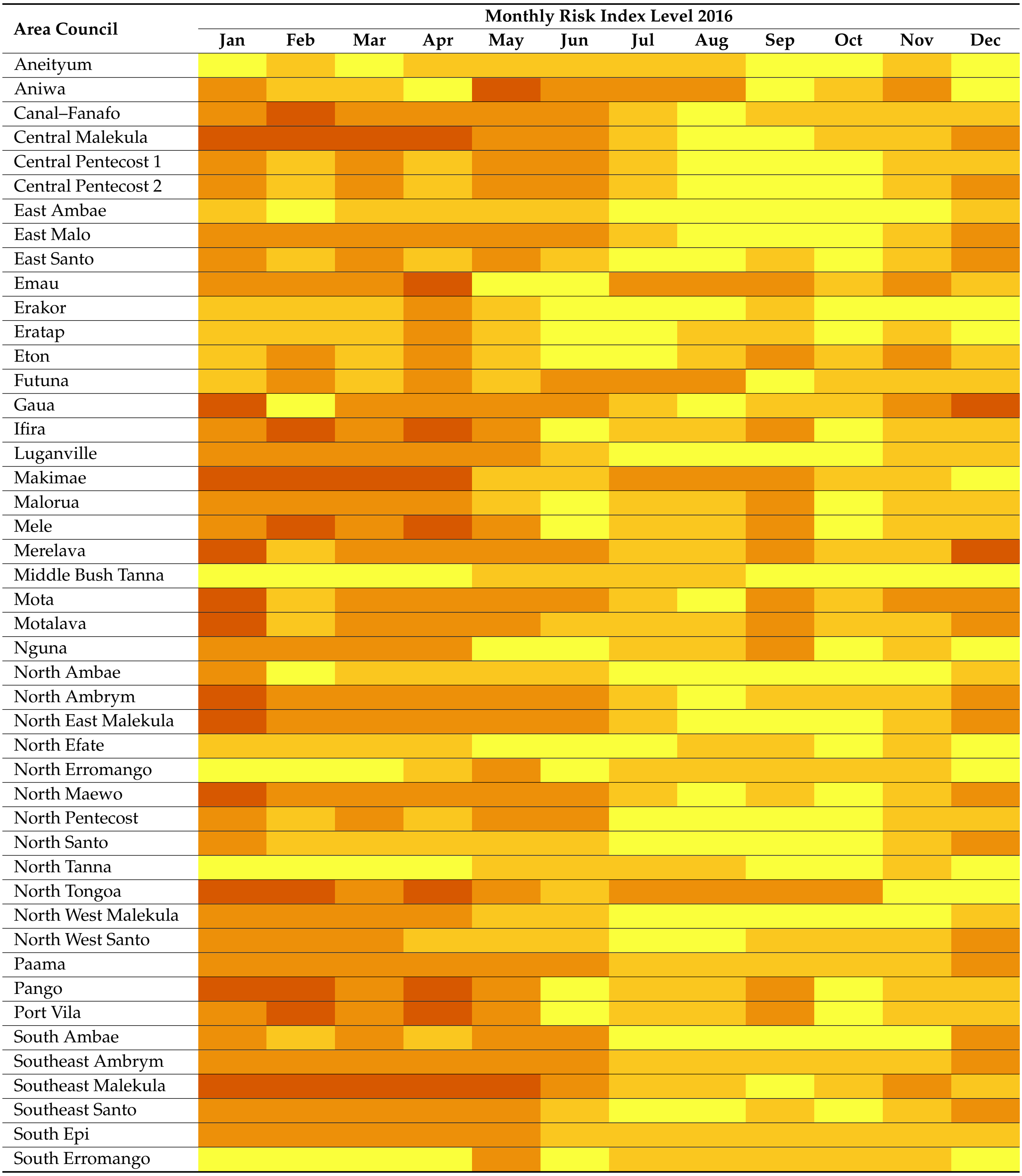
Area Council	**Monthly Risk Index Level 2015**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Aneityum	🟨	🟡	🟨	🟡	🟨	🟨	🟡	🟡	🟡	🟨	🟡	🟡
Aniwa	🟨	🟨	🟧	🟧	🟧	🟨	🟨	🟡	🟨	🟨	🟨	🟨
Canal–Fanafo	🟧	🟧	🟫	🟨	🟧	🟧	🟧	🟨	🟧	🟧	🟫	🟧
Central Malekula	🟧	🟧	🟫	🟧	🟧	🟨	🟧	🟨	🟧	🟨	🟧	🟨
Central Pentecost 1	🟧	🟧	🟧	🟡	🟨	🟨	🟧	🟧	🟧	🟧	🟧	🟨
Central Pentecost 2	🟧	🟧	🟧	🟡	🟨	🟨	🟧	🟨	🟧	🟧	🟧	🟨
East Ambae	🟧	🟨	🟨	🟡	🟡	🟡	🟨	🟨	🟨	🟨	🟧	🟨
East Malo	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟧
East Santo	🟧	🟧	🟧	🟨	🟨	🟨	🟧	🟨	🟧	🟧	🟧	🟨
Emau	🟨	🟨	🟨	🟧	🟧	🟨	🟧	🟧	🟧	🟨	🟧	🟨
Erakor	🟡	🟡	🟨	🟨	🟨	🟡	🟡	🟨	🟡	🟡	🟨	🟡
Eratap	🟨	🟡	🟨	🟨	🟨	🟨	🟨	🟧	🟡	🟡	🟧	🟨
Eton	🟨	🟡	🟨	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟧	🟨
Futuna	🟡	🟨	🟧	🟨	🟧	🟨	🟨	🟡	🟧	🟨	🟨	🟨
Gaua	🟫	🟫	🟧	🟧	🟧	🟧	🟫	🟧	🟧	🟧	🟫	🟧
Ifira	🟨	🟡	🟨	🟧	🟧	🟨	🟨	🟧	🟨	🟡	🟧	🟧
Luganville	🟨	🟨	🟧	🟨	🟨	🟨	🟧	🟨	🟧	🟧	🟧	🟨
Makimae	🟨	🟨	🟧	🟧	🟫	🟨	🟧	🟧	🟧	🟧	🟫	🟨
Malorua	🟨	🟡	🟨	🟧	🟧	🟨	🟨	🟨	🟧	🟨	🟧	🟨
Mele	🟨	🟡	🟨	🟧	🟧	🟨	🟨	🟨	🟨	🟡	🟧	🟧
Merelava	🟫	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧

Table A2. *Cont.*

Area Council	**Monthly Risk Index Level 2015**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Middle Bush Tanna	░	░	▒	▒	▒	▒	░	░	░	░	░	░
Mota	▓	▓	▓	▓	░	▒	▓	▒	▓	▓	▓	▒
Motalava	█	▓	▒	▓	░	▒	▓	▓	▓	▓	▓	▒
Nguna	▒	░	▒	▓	▓	░	▒	▒	▒	░	▓	░
North Ambae	▒	▒	▒	▒	░	░	▒	▒	▒	▒	▓	▒
North Ambrym	█	▓	▓	▒	▓	▓	▓	▓	▓	▓	▓	▒
North East Malekula	▓	▓	█	▒	▓	▒	▓	▒	▓	▓	▓	▒
North Efate	░	░	░	▒	▒	░	▒	▒	▒	░	▒	░
North Erromango	░	░	▒	▓	▒	░	░	▒	▒	▒	░	░
North Maewo	█	▓	▓	▒	▒	▒	▓	▓	▒	▓	▓	▓
North Pentecost	▓	▓	▒	░	▒	▒	▓	▒	▒	▓	▓	▒
North Santo	▒	▒	▓	░	░	▒	▒	░	▒	▒	▓	▒
North Tanna	░	░	▒	▒	▒	▒	░	░	▒	░	░	░
North Tongoa	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
North West Malekula	▒	▒	▓	▒	░	░	▒	░	▒	▒	▒	▒
North West Santo	▒	▒	▒	▒	▒	▒	▒	░	▒	▒	▓	▒
Paama	▓	▓	▓	▒	▓	▒	▓	▓	▓	▓	▓	▒
Pango	▒	░	▒	▓	▓	▒	▒	▓	▒	░	▓	▒
Port Vila	▒	░	▒	▓	▓	▒	▒	▓	▒	░	▓	▓
South Ambae	▒	▒	▓	░	░	▒	▒	▒	▒	▒	▓	▒
Southeast Ambrym	▓	▓	▓	▒	▓	▒	▓	▓	▓	▓	▓	▒
Southeast Malekula	▓	▓	█	▒	▓	▒	▓	▒	▓	▓	▓	▒
Southeast Santo	▒	▓	▓	▒	▒	▒	▓	▒	▓	▓	▓	▒
South Epi	▒	▒	▓	▒	▓	▒	▓	▓	▒	▒	▓	▒
South Erromango	░	░	▒	▓	▒	░	░	░	▒	░	░	▒
South Maewo	█	▓	▓	▒	░	▒	▓	▓	▓	█	█	▓
South Malekula	░	▒	▒	▒	▒	▒	▒	▒	▒	░	▒	▒
South Pentecost	█	█	▓	░	▒	▒	▓	▓	▓	▓	▓	▓
South Santo	▓	▓	▓	▒	▒	▒	▓	░	▒	▒	▓	▓
South Tanna	░	░	▓	▓	▒	▒	▒	░	▒	▒	▒	░
South West Malekula	▒	▓	▓	▓	▒	▒	▒	░	▒	░	▓	▒
South West Tanna	░	░	▓	▓	▒	▒	▒	░	▒	▒	▒	░
Tongariki	▓	▒	▓	▓	▓	▓	▓	▓	▓	▓	▓	▓
Torres	▓	▒	▒	▓	▓	▓	▓	▒	▒	▓	▓	▓
Ureparapara	▓	▓	▒	▓	░	□	▓	▒	▓	▒	▓	▒
Vanua Lava	▓	▓	▓	▒	░	□	▓	▒	▒	▒	▓	▒
Varisu	▒	▒	▓	▒	▒	▒	▒	▒	▒	▒	▓	▒
Vermali	░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
Vermaul	░	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
West Ambae	▓	▓	▓	▓	▒	▒	▓	▒	▓	▓	▓	▒
West Ambrym	▓	▓	▓	▒	▓	▓	▓	▓	▓	▒	▓	▒
West Malo	▒	▓	▓	▒	▒	▒	▓	░	▓	▓	▓	▒
West Santo	▒	░	▒	▓	▒	▒	▒	░	▒	▒	▓	▓
West Tanna	░	░	▒	▒	▒	▒	░	░	▒	░	░	░
Whitesands	░	░	▓	▓	▒	▒	▒	░	▒	░	▒	░

Appendix C

Table A3. Monthly risk index levels for Vanuatu area councils throughout the year of 2016. Risk index levels are categorised into five severity classes: Extreme (0.81–1.00) 🟥, Severe (0.61–0.80) 🟧, Moderate (0.41–0.60) 🔶, Mild (0.21–0.40) 🟡, and Very Mild (0.01–0.20) 🟨.



Area Council	**Monthly Risk Index Level 2016**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Aneityum	🟨	🟡	🟨	🟡	🟡	🟡	🟡	🟡	🟨	🟨	🟡	🟨
Aniwa	🔶	🟡	🟡	🟨	🟧	🔶	🔶	🔶	🟨	🟡	🔶	🟨
Canal–Fanafo	🔶	🟧	🔶	🔶	🔶	🔶	🟡	🟨	🟡	🟡	🟡	🟡
Central Malekula	🟧	🟧	🟧	🟧	🔶	🔶	🟡	🟨	🟨	🟡	🟡	🔶
Central Pentecost 1	🔶	🟡	🔶	🟡	🔶	🔶	🟡	🟨	🟨	🟨	🟡	🟡
Central Pentecost 2	🔶	🟡	🔶	🟡	🔶	🔶	🟡	🟨	🟨	🟨	🟡	🔶
East Ambae	🟡	🟨	🟡	🟡	🟡	🟡	🟨	🟨	🟨	🟨	🟨	🟡
East Malo	🔶	🔶	🔶	🔶	🔶	🔶	🟡	🟨	🟨	🟨	🟡	🔶
East Santo	🔶	🟡	🔶	🟡	🔶	🟡	🟨	🟨	🟡	🟨	🟡	🔶
Emau	🔶	🔶	🔶	🟧	🟨	🟨	🔶	🔶	🔶	🟡	🔶	🟡
Erakor	🟡	🟡	🟡	🔶	🟡	🟨	🟨	🟨	🟡	🟨	🟨	🟨
Eratap	🟡	🟡	🟡	🔶	🟡	🟨	🟨	🟡	🟡	🟨	🟡	🟨
Eton	🟡	🔶	🟡	🔶	🟡	🟨	🟨	🟡	🔶	🟡	🔶	🟡
Futuna	🟡	🔶	🟡	🔶	🟡	🔶	🔶	🔶	🟨	🟡	🟡	🟡
Gaua	🟧	🟨	🔶	🔶	🔶	🔶	🟡	🟨	🟡	🟡	🔶	🟧
Ifira	🔶	🟧	🔶	🟧	🔶	🟨	🟡	🟡	🔶	🟨	🟡	🟡
Luganville	🔶	🔶	🔶	🔶	🔶	🟡	🟨	🟨	🟨	🟨	🟡	🟡
Makimae	🟧	🟧	🟧	🟧	🟡	🟡	🔶	🔶	🔶	🟡	🟡	🟨
Malorua	🔶	🔶	🔶	🔶	🟡	🟨	🟡	🟡	🔶	🟨	🟡	🟡
Mele	🔶	🟧	🔶	🟧	🔶	🟨	🟡	🟡	🔶	🟨	🟡	🟡
Merelava	🟧	🟡	🔶	🔶	🔶	🔶	🟡	🟡	🔶	🟡	🟡	🟧
Middle Bush Tanna	🟨	🟨	🟨	🟨	🟡	🟡	🟡	🟡	🟨	🟨	🟨	🟨
Mota	🟧	🟡	🔶	🔶	🔶	🔶	🟡	🟨	🔶	🟡	🔶	🔶
Motalava	🟧	🟡	🔶	🔶	🔶	🟡	🟡	🟡	🔶	🟡	🟡	🔶
Nguna	🔶	🔶	🔶	🔶	🟨	🟨	🟡	🟡	🔶	🟨	🟡	🟨
North Ambae	🔶	🟨	🟡	🟡	🟡	🟡	🟨	🟨	🟨	🟨	🟨	🟡
North Ambrym	🟧	🔶	🔶	🔶	🔶	🔶	🟡	🟨	🟡	🟡	🟡	🔶
North East Malekula	🟧	🔶	🔶	🔶	🔶	🔶	🟡	🟨	🟨	🟨	🟡	🔶
North Efate	🟡	🟡	🟡	🟡	🟨	🟨	🟨	🟡	🟡	🟨	🟡	🟨
North Erromango	🟨	🟨	🟨	🟡	🔶	🟨	🟡	🟡	🟡	🟡	🟡	🟨
North Maewo	🟧	🔶	🔶	🔶	🔶	🔶	🟡	🟨	🟡	🟨	🟡	🔶
North Pentecost	🔶	🟡	🔶	🟡	🔶	🔶	🟨	🟨	🟨	🟨	🟡	🟡
North Santo	🔶	🟡	🟡	🟡	🟡	🟡	🟨	🟨	🟨	🟨	🟡	🔶
North Tanna	🟨	🟨	🟨	🟨	🟡	🟡	🟡	🟡	🟨	🟨	🟡	🟨
North Tongoa	🟧	🟧	🔶	🟧	🔶	🟡	🔶	🔶	🔶	🔶	🟨	🟨
North West Malekula	🔶	🔶	🔶	🔶	🟡	🟡	🟨	🟨	🟨	🟨	🟨	🟡
North West Santo	🔶	🔶	🔶	🟡	🟡	🟡	🟨	🟨	🟡	🟡	🟡	🔶
Paama	🔶	🔶	🔶	🔶	🔶	🔶	🟡	🟡	🟡	🟡	🟡	🔶
Pango	🟧	🟧	🔶	🟧	🔶	🟨	🟡	🟡	🔶	🟨	🟡	🟡
Port Vila	🔶	🟧	🔶	🟧	🔶	🟨	🟡	🟡	🔶	🟨	🟡	🟡
South Ambae	🔶	🟡	🔶	🟡	🔶	🔶	🟨	🟨	🟨	🟨	🟨	🔶
Southeast Ambrym	🔶	🔶	🔶	🔶	🔶	🔶	🟡	🟡	🟡	🟡	🟡	🔶
Southeast Malekula	🟧	🟧	🟧	🟧	🟧	🔶	🟡	🟡	🟨	🟡	🔶	🟡
Southeast Santo	🔶	🔶	🔶	🔶	🔶	🟡	🟨	🟨	🟡	🟨	🟡	🔶
South Epi	🔶	🔶	🔶	🔶	🔶	🟡	🟡	🟡	🟡	🟡	🟡	🟡
South Erromango	🟨	🟨	🟨	🟨	🔶	🟨	🟡	🟡	🟡	🟡	🟡	🟨

Table A3. *Cont.*

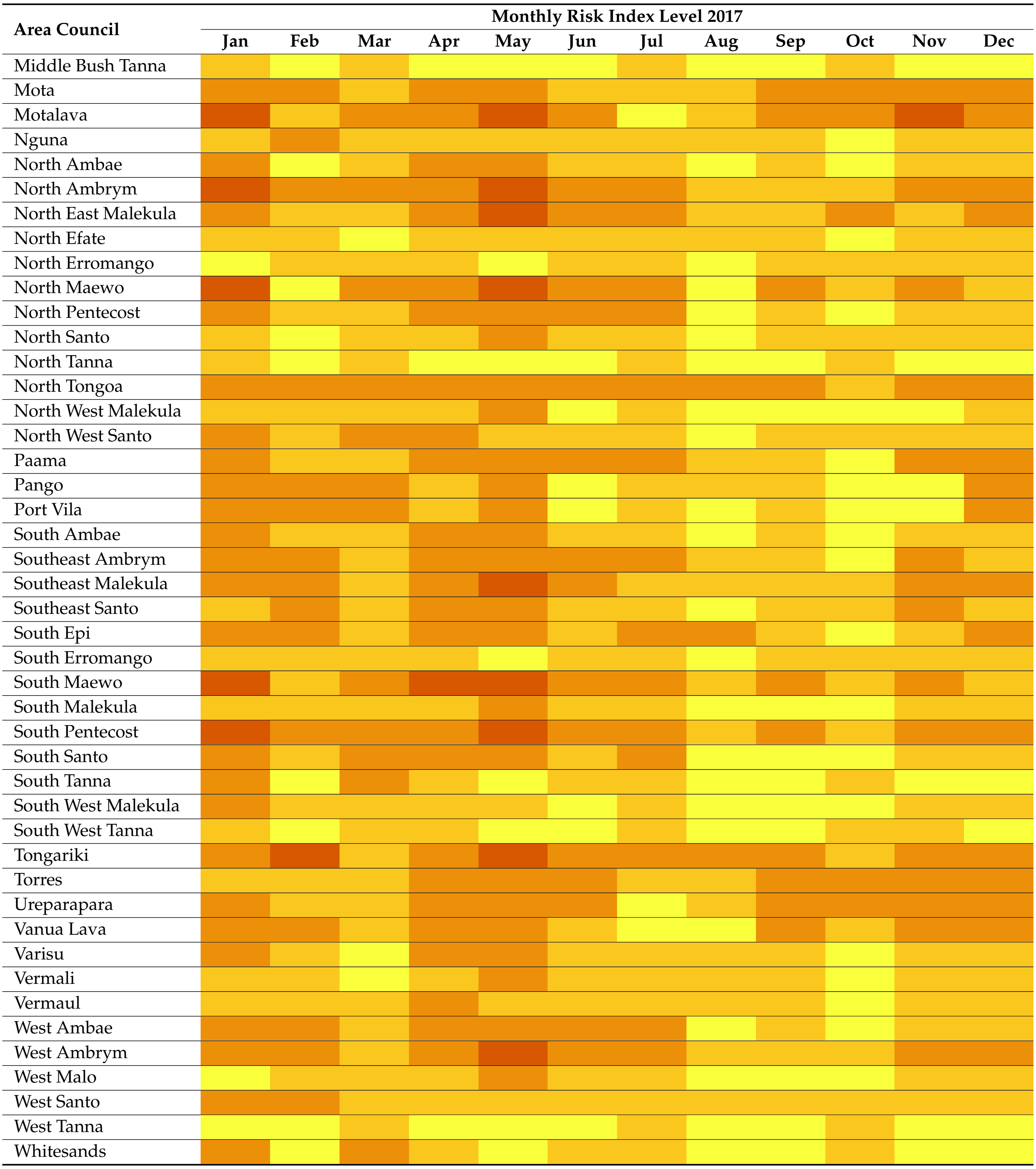
Area Council	**Monthly Risk Index Level 2016**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
South Maewo	🟠	🟠	🟠	🟡	🟠	🟠	🟡	🟨	🟡	🟨	🟡	🟠
South Malekula	🟠	🟠	🟡	🟠	🟡	🟡	🟡	🟨	🟨	🟨	🟡	🟨
South Pentecost	🟧	🟠	🟠	🟠	🟠	🟠	🟡	🟨	🟡	🟨	🟡	🟠
South Santo	🟠	🟠	🟧	🟠	🟠	🟡	🟡	🟨	🟡	🟡	🟡	🟠
South Tanna	🟨	🟡	🟨	🟡	🟠	🟠	🟡	🟠	🟨	🟡	🟡	🟨
South West Malekula	🟠	🟠	🟠	🟠	🟠	🟡	🟡	🟨	🟨	🟨	🟡	🟡
South West Tanna	🟡	🟡	🟨	🟨	🟠	🟡	🟡	🟡	🟨	🟡	🟡	🟨
Tongariki	🟧	🟧	🟠	🟧	🟡	🟨	🟠	🟠	🟠	🟠	🟡	🟨
Torres	🟠	🟨	🟠	🟠	🟠	🟠	🟡	🟡	🟡	🟡	🟡	🟠
Ureparapara	🟧	🟨	🟠	🟠	🟠	🟡	🟨	🟨	🟡	🟡	🟡	🟠
Vanua Lava	🟠	🟨	🟡	🟡	🟠	🟡	🟨	🟨	🟡	🟨	🟡	🟠
Varisu	🟠	🟠	🟡	🟠	🟠	🟡	🟡	🟨	🟡	🟡	🟡	🟡
Vermali	🟡	🟠	🟡	🟠	🟡	🟡	🟡	🟨	🟨	🟨	🟨	🟨
Vermaul	🟠	🟠	🟠	🟠	🟠	🟡	🟡	🟨	🟡	🟨	🟡	🟨
West Ambae	🟠	🟡	🟠	🟠	🟠	🟠	🟡	🟨	🟨	🟨	🟡	🟠
West Ambrym	🟠	🟠	🟠	🟧	🟠	🟠	🟡	🟨	🟨	🟨	🟡	🟠
West Malo	🟠	🟠	🟠	🟡	🟠	🟡	🟨	🟨	🟨	🟨	🟨	🟠
West Santo	🟠	🟠	🟠	🟠	🟡	🟡	🟨	🟨	🟡	🟨	🟡	🟠
West Tanna	🟡	🟨	🟨	🟨	🟡	🟡	🟨	🟡	🟨	🟡	🟡	🟨
Whitesands	🟨	🟨	🟨	🟨	🟠	🟡	🟡	🟠	🟨	🟨	🟡	🟨

Appendix D

Table A4. Monthly risk index levels for Vanuatu area councils throughout the year of 2017. Risk index levels are categorised into five severity classes: Extreme (0.81–1.00) 🟥, Severe (0.61–0.80) 🟧, Moderate (0.41–0.60) 🟠, Mild (0.21–0.40) 🟡, and Very Mild (0.01–0.20) 🟨.

Area Council	**Monthly Risk Index Level 2017**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Aneityum	🟨	🟨	🟡	🟡	🟨	🟡	🟡	🟡	🟨	🟡	🟨	🟨
Aniwa	🟠	🟠	🟠	🟡	🟡	🟠	🟠	🟡	🟨	🟠	🟨	🟨
Canal–Fanafo	🟡	🟡	🟠	🟧	🟧	🟠	🟠	🟨	🟡	🟡	🟠	🟠
Central Malekula	🟠	🟠	🟡	🟠	🟧	🟠	🟠	🟡	🟨	🟡	🟠	🟠
Central Pentecost 1	🟠	🟡	🟡	🟠	🟠	🟠	🟠	🟡	🟡	🟨	🟡	🟡
Central Pentecost 2	🟠	🟠	🟡	🟠	🟠	🟠	🟠	🟡	🟡	🟨	🟡	🟡
East Ambae	🟠	🟨	🟡	🟠	🟠	🟡	🟡	🟨	🟡	🟨	🟡	🟡
East Malo	🟡	🟡	🟡	🟠	🟠	🟠	🟠	🟡	🟡	🟡	🟠	🟠
East Santo	🟠	🟡	🟡	🟠	🟠	🟠	🟡	🟨	🟡	🟡	🟠	🟡
Emau	🟠	🟠	🟡	🟠	🟠	🟠	🟠	🟠	🟠	🟡	🟠	🟠
Erakor	🟡	🟡	🟡	🟨	🟡	🟨	🟨	🟨	🟨	🟨	🟨	🟡
Eratap	🟠	🟡	🟡	🟨	🟡	🟡	🟨	🟡	🟡	🟨	🟨	🟡
Eton	🟠	🟠	🟡	🟠	🟠	🟠	🟠	🟠	🟠	🟨	🟡	🟠
Futuna	🟠	🟠	🟠	🟡	🟡	🟠	🟠	🟨	🟡	🟠	🟡	🟨
Gaua	🟡	🟨	🟠	🟧	🟧	🟠	🟠	🟡	🟠	🟠	🟧	🟠
Ifira	🟠	🟠	🟠	🟡	🟠	🟨	🟡	🟨	🟡	🟨	🟨	🟠
Luganville	🟡	🟡	🟡	🟠	🟠	🟡	🟡	🟨	🟡	🟡	🟡	🟡
Makimae	🟧	🟠	🟡	🟠	🟧	🟠	🟠	🟠	🟠	🟡	🟠	🟠
Malorua	🟡	🟠	🟡	🟡	🟠	🟡	🟡	🟡	🟡	🟨	🟨	🟠
Mele	🟠	🟠	🟠	🟡	🟡	🟨	🟡	🟨	🟡	🟨	🟨	🟠
Merelava	🟠	🟨	🟠	🟧	🟧	🟠	🟠	🟡	🟠	🟠	🟠	🟠

Table A4. *Cont.*



Area Council	**Monthly Risk Index Level 2017**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Middle Bush Tanna	▒	░	▒	░	░	░	▒	░	░	▒	░	░
Mota	▓	▓	▒	▓	▓	▒	▒	▒	▓	▓	▓	▓
Motalava	█	▒	▓	▓	█	▓	░	▒	▓	▓	█	▓
Nguna	▒	▓	▒	▒	▒	▒	▒	▒	▒	░	▒	▒
North Ambae	▓	░	▒	▓	▓	▒	▒	░	▒	░	▒	▒
North Ambrym	█	▓	▓	▓	█	▓	▓	▒	▒	▒	▓	▓
North East Malekula	▓	▒	▒	▓	█	▓	▓	▒	▒	▓	▒	▓
North Efate	▒	▒	░	▒	▒	▒	▒	▒	▒	░	▒	▒
North Erromango	░	▒	▒	▒	░	▒	▒	░	▒	▒	▒	▒
North Maewo	█	░	▓	▓	█	▓	▓	░	▓	▒	▓	▒
North Pentecost	▓	▒	▒	▓	▓	▓	▓	░	▒	░	▒	▒
North Santo	▒	░	▒	▒	▓	▒	▒	░	▒	▒	▒	▒
North Tanna	▒	░	▒	░	░	░	▒	░	░	▒	░	░
North Tongoa	▓	▓	▓	▓	▓	▓	▓	▓	▓	▒	▓	▓
North West Malekula	▒	▒	▒	▒	▓	░	▒	░	░	░	░	▒
North West Santo	▓	▒	▓	▓	▒	▒	▒	░	▒	▒	▒	▒
Paama	▓	▒	▒	▓	▓	▓	▓	▒	▒	░	▓	▓
Pango	▓	▓	▓	▒	▓	░	▒	▒	▒	░	░	▓
Port Vila	▓	▓	▓	▒	▓	░	▒	░	▒	░	░	▓
South Ambae	▓	▒	▒	▓	▓	▒	▒	░	▒	░	▒	▒
Southeast Ambrym	▓	▓	▒	▓	▓	▓	▓	▒	▒	░	▓	▒
Southeast Malekula	▓	▓	▒	▓	█	▓	▒	▒	▒	▒	▓	▓
Southeast Santo	▒	▓	▒	▓	▓	▒	▒	░	▒	▒	▓	▒
South Epi	▓	▓	▒	▓	▓	▒	▓	▓	▒	░	▒	▓
South Erromango	▒	▒	▒	▒	░	▒	▒	░	▒	▒	▒	▒
South Maewo	█	▒	▓	█	█	▓	▓	▒	▓	▒	▓	▒
South Malekula	▒	▒	▒	▒	▓	▒	▒	░	░	░	▒	▒
South Pentecost	█	▓	▓	▓	█	▓	▓	▒	▓	▒	▓	▓
South Santo	▓	▒	▓	▓	▓	▒	▓	░	░	░	▒	▒
South Tanna	▓	░	▓	▒	░	▒	▒	░	░	▒	░	░
South West Malekula	▓	▒	▒	▒	▒	░	▒	░	░	░	▒	▒
South West Tanna	▒	░	▒	▒	░	░	▒	░	░	▒	▒	░
Tongariki	▓	█	▒	▓	█	▓	▓	▓	▓	▒	▓	▓
Torres	▒	▒	▒	▓	▓	▓	▒	▒	▓	▓	▓	▓
Ureparapara	▓	▒	▒	▓	▓	▓	░	▒	▓	▓	▓	▓
Vanua Lava	▓	▓	▒	▓	▓	▒	░	░	▓	▒	▓	▓
Varisu	▓	▒	░	▓	▓	▒	▒	▒	▒	░	▒	▒
Vermali	▒	▒	░	▒	▓	▒	▒	▒	▒	░	▒	▒
Vermaul	▒	▒	▒	▓	▒	▒	▒	▒	▒	░	▒	▒
West Ambae	▓	▓	▒	▓	▓	▓	▓	░	▒	░	▒	▒
West Ambrym	▓	▓	▒	▓	█	▓	▓	▒	▒	▒	▓	▓
West Malo	░	▒	▒	▒	▓	▒	▒	░	░	░	▒	▒
West Santo	▓	▓	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
West Tanna	░	░	▒	░	░	░	▒	░	░	▒	░	░
Whitesands	▓	░	▓	▒	░	▒	▒	░	░	▒	░	░

Appendix E

Table A5. Monthly risk index levels for Vanuatu area councils throughout the year of 2020. Risk index levels are categorised into five severity classes: Extreme (0.81–1.00) 🟥, Severe (0.61–0.80) 🟧, Moderate (0.41–0.60) 🔶, Mild (0.21–0.40) 🟡, and Very Mild (0.01–0.20) 🟨.

Area Council	**Monthly Hazard Index Level 2020**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Aneityum	🟨	🟡	🟨	🟡	🟨	🟨	🟨	🟡	🟨	🟡	🟨	🟨
Aniwa	🟨	🟡	🟡	🟡	🟡	🟡	🟡	🔶	🟨	🟡	🟡	🟡
Canal–Fanafo	🔶	🟧	🟧	🟡	🔶	🔶	🟧	🟡	🟧	🟡	🟡	🔶
Central Malekula	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🟡	🔶	🟡	🔶	🔶
Central Pentecost 1	🔶	🟡	🟡	🟡	🔶	🔶	🔶	🟨	🔶	🟡	🟡	🔶
Central Pentecost 2	🔶	🔶	🟡	🟡	🔶	🔶	🔶	🟨	🔶	🟨	🟡	🔶
East Ambae	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🔶	🟡	🟨	🟡
East Malo	🔶	🔶	🔶	🟡	🔶	🔶	🔶	🟡	🔶	🟡	🟡	🔶
East Santo	🔶	🔶	🔶	🟡	🔶	🔶	🔶	🟨	🔶	🟨	🟡	🔶
Emau	🔶	🔶	🔶	🔶	🟡	🟡	🟨	🟡	🔶	🟨	🔶	🔶
Erakor	🟡	🟨	🟡	🟡	🟨	🟨	🟨	🟨	🟡	🟨	🟨	🟡
Eratap	🟡	🟨	🟡	🔶	🟡	🟨	🟨	🟨	🔶	🟡	🟡	🟡
Eton	🟡	🟡	🔶	🟡	🟨	🟨	🟨	🟨	🔶	🟨	🔶	🔶
Futuna	🟨	🟡	🟡	🔶	🟨	🟡	🟡	🟡	🟨	🟡	🟨	🟡
Gaua	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🟡	🔶	🔶
Ifira	🔶	🟡	🔶	🔶	🟡	🟨	🟡	🟡	🔶	🟡	🟡	🔶
Luganville	🔶	🔶	🔶	🟡	🔶	🔶	🔶	🟡	🔶	🟡	🟡	🔶
Makimae	🔶	🔶	🟧	🟧	🔶	🔶	🔶	🟡	🟧	🟨	🔶	🟧
Malorua	🟡	🟡	🔶	🔶	🟡	🟡	🟡	🟡	🔶	🟨	🟨	🔶
Mele	🔶	🟡	🔶	🔶	🟡	🟨	🟡	🟡	🔶	🟨	🟡	🔶
Merelava	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🟡	🟡	🔶
Middle Bush Tanna	🟨	🟨	🟨	🟡	🟨	🟨	🟨	🟨	🟨	🟡	🟨	🟨
Mota	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🟡	🔶
Motalava	🟧	🔶	🟧	🔶	🟧	🟧	🔶	🔶	🔶	🔶	🔶	🔶
Nguna	🟡	🟡	🔶	🟡	🟡	🟡	🟡	🟨	🔶	🟨	🟡	🔶
North Ambae	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟡	🟨	🟡
North Ambrym	🔶	🔶	🔶	🟡	🔶	🔶	🔶	🟨	🔶	🟡	🔶	🔶
North East Malekula	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🟡	🔶	🟡	🔶	🔶
North Efate	🟡	🟡	🟡	🟡	🟡	🟨	🟨	🟨	🟡	🟨	🟡	🟡
North Erromango	🟨	🟨	🟡	🟡	🟨	🟨	🟨	🟨	🟡	🟡	🟡	🟨
North Maewo	🔶	🔶	🟡	🔶	🔶	🔶	🔶	🟡	🔶	🟨	🟡	🔶
North Pentecost	🔶	🟡	🟡	🟡	🔶	🔶	🔶	🟨	🔶	🟡	🟡	🔶
North Santo	🟡	🟡	🟡	🟨	🟡	🟡	🟡	🟨	🟡	🟨	🟨	🟡
North Tanna	🟨	🟨	🟡	🟡	🟨	🟨	🟨	🟨	🟨	🟡	🟨	🟨
North Tongoa	🔶	🔶	🔶	🔶	🟡	🟡	🔶	🔶	🔶	🟡	🔶	🔶
North West Malekula	🟡	🟡	🔶	🟡	🟡	🟡	🟡	🟨	🟡	🟨	🟡	🟡
North West Santo	🟡	🟡	🟡	🟨	🟡	🟡	🟡	🟨	🟡	🟨	🟨	🟡
Paama	🔶	🔶	🔶	🟡	🟡	🔶	🔶	🟡	🔶	🟡	🔶	🔶
Pango	🔶	🟡	🔶	🔶	🟡	🟨	🟡	🟡	🔶	🟡	🟡	🔶
Port Vila	🔶	🟡	🔶	🟧	🟡	🟨	🟡	🟡	🟧	🟡	🟡	🔶
South Ambae	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟡	🟨	🟡
Southeast Ambrym	🔶	🔶	🔶	🟡	🔶	🔶	🔶	🟡	🔶	🟡	🟡	🔶
Southeast Malekula	🔶	🔶	🔶	🔶	🔶	🔶	🔶	🟡	🔶	🟡	🔶	🟧
Southeast Santo	🔶	🔶	🔶	🟡	🔶	🔶	🔶	🟡	🔶	🟡	🟡	🔶
South Epi	🟡	🔶	🔶	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡
South Erromango	🟨	🟨	🟡	🟡	🟨	🟨	🟨	🟨	🟡	🟡	🟨	🟨

Table A5. *Cont.*

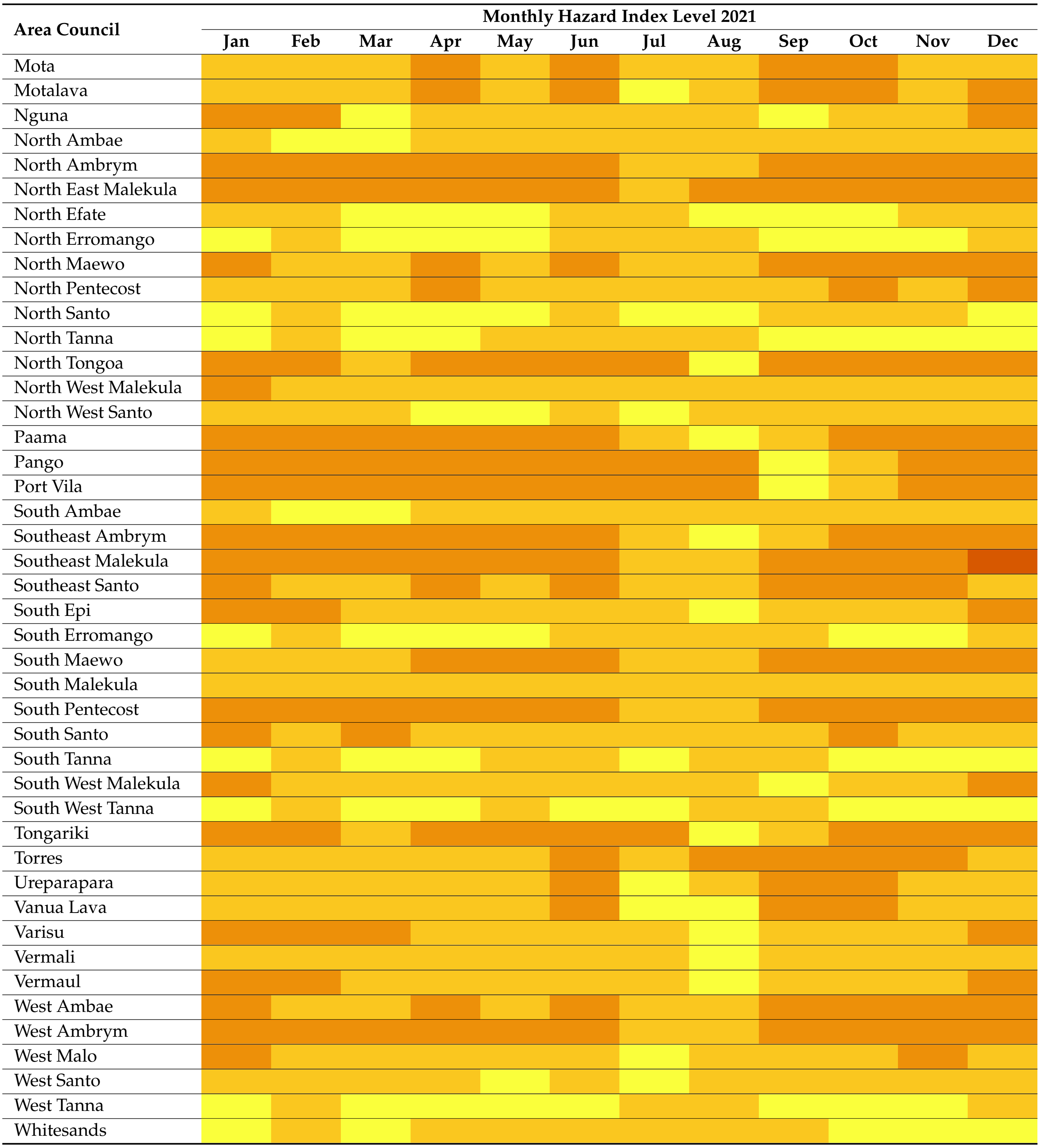
Area Council	**Monthly Hazard Index Level 2020**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
South Maewo	🟧	🟡	🟡	🟧	🟧	🟧	🟧	🟡	🟧	🟡	🟡	🟧
South Malekula	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟡	🟡	🟡
South Pentecost	🟧	🟧	🟧	🟡	🟧	🟧	🟧	🟡	🟧	🟡	🟧	🟧
South Santo	🟧	🟡	🟧	🟨	🟧	🟧	🟧	🟨	🟧	🟨	🟡	🟧
South Tanna	🟨	🟨	🟡	🟡	🟨	🟨	🟡	🟡	🟨	🟡	🟨	🟨
South West Malekula	🟡	🟡	🟧	🟨	🟡	🟡	🟡	🟨	🟡	🟡	🟡	🟡
South West Tanna	🟨	🟨	🟨	🟡	🟨	🟨	🟨	🟨	🟨	🟡	🟨	🟨
Tongariki	🟧	🟧	🟧	🟧	🟡	🟡	🟧	🟡	🟧	🟡	🟧	🟧
Torres	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟡	🟡	🟧
Ureparapara	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟡	🟡	🟧
Vanua Lava	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟡	🟡	🟧
Varisu	🟡	🟧	🟧	🟡	🟡	🟡	🟡	🟨	🟡	🟨	🟡	🟡
Vermali	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟨	🟡	🟡
Vermaul	🟡	🟡	🟧	🟡	🟡	🟡	🟡	🟨	🟡	🟨	🟡	🟡
West Ambae	🟧	🟧	🟧	🟡	🟧	🟧	🟧	🟡	🟧	🟡	🟡	🟧
West Ambrym	🟧	🟧	🟧	🟡	🟧	🟧	🟧	🟡	🟧	🟡	🟧	🟧
West Malo	🟧	🟧	🟧	🟡	🟧	🟧	🟧	🟨	🟧	🟨	🟨	🟧
West Santo	🟡	🟡	🟡	🟨	🟡	🟡	🟡	🟨	🟡	🟡	🟡	🟡
West Tanna	🟨	🟨	🟡	🟨	🟨	🟨	🟨	🟨	🟨	🟡	🟨	🟨
Whitesands	🟨	🟨	🟡	🟡	🟨	🟨	🟨	🟡	🟨	🟡	🟨	🟨

Appendix F

Table A6. Monthly risk index levels for Vanuatu area councils throughout the year of 2021. Risk index levels are categorised into five severity classes: Extreme (0.81–1.00) 🟥, Severe (0.61–0.80) 🟫, Moderate (0.41–0.60) 🟧, Mild (0.21–0.40) 🟡, and Very Mild (0.01–0.20) 🟨.

Area Council	**Monthly Hazard Index Level 2021**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Aneityum	🟨	🟡	🟡	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Aniwa	🟡	🟧	🟡	🟧	🟧	🟧	🟧	🟡	🟡	🟨	🟨	🟡
Canal–Fanafo	🟫	🟧	🟧	🟧	🟡	🟧	🟡	🟧	🟧	🟧	🟫	🟡
Central Malekula	🟧	🟧	🟧	🟧	🟧	🟧	🟡	🟧	🟧	🟧	🟧	🟧
Central Pentecost 1	🟧	🟡	🟡	🟧	🟡	🟡	🟡	🟡	🟡	🟧	🟡	🟧
Central Pentecost 2	🟧	🟡	🟡	🟧	🟡	🟡	🟡	🟡	🟡	🟧	🟡	🟧
East Ambae	🟡	🟨	🟨	🟡	🟡	🟡	🟡	🟡	🟡	🟧	🟡	🟡
East Malo	🟧	🟡	🟧	🟧	🟡	🟧	🟡	🟧	🟧	🟧	🟧	🟡
East Santo	🟡	🟡	🟡	🟧	🟡	🟧	🟡	🟡	🟡	🟧	🟧	🟡
Emau	🟧	🟧	🟡	🟡	🟡	🟧	🟧	🟡	🟨	🟧	🟧	🟧
Erakor	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟨	🟡	🟡
Eratap	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟧	🟨	🟡	🟡	🟡
Eton	🟧	🟧	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟨	🟡	🟡
Futuna	🟡	🟧	🟡	🟧	🟡	🟡	🟨	🟨	🟡	🟨	🟨	🟡
Gaua	🟡	🟡	🟧	🟧	🟡	🟧	🟡	🟡	🟧	🟧	🟡	🟧
Ifira	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟡	🟧	🟧
Luganville	🟧	🟡	🟡	🟧	🟡	🟧	🟡	🟡	🟡	🟧	🟧	🟡
Makimae	🟫	🟫	🟧	🟧	🟧	🟧	🟧	🟨	🟡	🟧	🟫	🟫
Malorua	🟧	🟧	🟡	🟡	🟨	🟧	🟧	🟡	🟨	🟡	🟧	🟧
Mele	🟧	🟧	🟧	🟡	🟨	🟧	🟧	🟧	🟨	🟡	🟧	🟧
Merelava	🟡	🟧	🟡	🟧	🟡	🟧	🟡	🟡	🟧	🟧	🟡	🟧
Middle Bush Tanna	🟨	🟡	🟨	🟨	🟡	🟡	🟨	🟡	🟨	🟨	🟨	🟨

Table A6. *Cont.*



Area Council	**Monthly Hazard Index Level 2021**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Mota	🟡	🟡	🟡	🟧	🟡	🟧	🟡	🟡	🟧	🟧	🟡	🟡
Motalava	🟡	🟡	🟡	🟧	🟡	🟧	🟨	🟡	🟧	🟧	🟡	🟧
Nguna	🟧	🟧	🟨	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟡	🟧
North Ambae	🟡	🟨	🟨	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡
North Ambrym	🟧	🟧	🟧	🟧	🟧	🟧	🟡	🟡	🟧	🟧	🟧	🟧
North East Malekula	🟧	🟧	🟧	🟧	🟧	🟧	🟡	🟧	🟧	🟧	🟧	🟧
North Efate	🟡	🟡	🟨	🟨	🟨	🟡	🟡	🟨	🟨	🟨	🟡	🟡
North Erromango	🟨	🟡	🟨	🟨	🟨	🟡	🟡	🟡	🟨	🟨	🟨	🟡
North Maewo	🟧	🟡	🟡	🟧	🟡	🟧	🟡	🟡	🟧	🟧	🟧	🟧
North Pentecost	🟡	🟡	🟡	🟧	🟡	🟡	🟡	🟡	🟡	🟧	🟡	🟧
North Santo	🟨	🟡	🟨	🟨	🟨	🟡	🟨	🟨	🟡	🟡	🟡	🟨
North Tanna	🟨	🟡	🟨	🟨	🟡	🟡	🟡	🟡	🟨	🟨	🟨	🟨
North Tongoa	🟧	🟧	🟡	🟧	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟧
North West Malekula	🟧	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡
North West Santo	🟡	🟡	🟡	🟨	🟨	🟡	🟨	🟡	🟡	🟡	🟡	🟡
Paama	🟧	🟧	🟧	🟧	🟧	🟧	🟡	🟨	🟡	🟧	🟧	🟧
Pango	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟡	🟧	🟧
Port Vila	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟨	🟡	🟧	🟧
South Ambae	🟡	🟨	🟨	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡
Southeast Ambrym	🟧	🟧	🟧	🟧	🟧	🟧	🟡	🟨	🟡	🟧	🟧	🟧
Southeast Malekula	🟧	🟧	🟧	🟧	🟧	🟧	🟡	🟡	🟧	🟧	🟧	🟥
Southeast Santo	🟧	🟡	🟡	🟧	🟡	🟧	🟡	🟡	🟧	🟧	🟧	🟡
South Epi	🟧	🟧	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟡	🟡	🟧
South Erromango	🟨	🟡	🟨	🟨	🟨	🟡	🟡	🟡	🟡	🟨	🟨	🟡
South Maewo	🟡	🟡	🟡	🟧	🟧	🟧	🟡	🟡	🟧	🟧	🟧	🟧
South Malekula	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡
South Pentecost	🟧	🟧	🟧	🟧	🟧	🟧	🟡	🟡	🟧	🟧	🟧	🟧
South Santo	🟧	🟡	🟧	🟡	🟡	🟡	🟡	🟡	🟡	🟧	🟡	🟡
South Tanna	🟨	🟡	🟨	🟨	🟡	🟡	🟨	🟡	🟡	🟨	🟨	🟨
South West Malekula	🟧	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟡	🟧
South West Tanna	🟨	🟡	🟨	🟨	🟡	🟨	🟨	🟡	🟡	🟨	🟨	🟨
Tongariki	🟧	🟧	🟡	🟧	🟧	🟧	🟧	🟨	🟡	🟧	🟧	🟧
Torres	🟡	🟡	🟡	🟡	🟡	🟧	🟡	🟧	🟧	🟧	🟧	🟡
Ureparapara	🟡	🟡	🟡	🟡	🟡	🟧	🟨	🟡	🟧	🟧	🟡	🟡
Vanua Lava	🟡	🟡	🟡	🟡	🟡	🟧	🟨	🟨	🟧	🟧	🟡	🟡
Varisu	🟧	🟧	🟧	🟡	🟡	🟡	🟡	🟨	🟡	🟡	🟡	🟧
Vermali	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟡	🟡	🟡
Vermaul	🟧	🟧	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟡	🟡	🟧
West Ambae	🟧	🟡	🟡	🟧	🟡	🟧	🟡	🟡	🟧	🟧	🟧	🟧
West Ambrym	🟧	🟧	🟧	🟧	🟧	🟧	🟡	🟡	🟧	🟧	🟧	🟧
West Malo	🟧	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟡	🟡	🟧	🟡
West Santo	🟡	🟡	🟡	🟡	🟨	🟡	🟨	🟡	🟡	🟡	🟡	🟡
West Tanna	🟨	🟡	🟨	🟨	🟨	🟨	🟡	🟡	🟨	🟨	🟨	🟡
Whitesands	🟨	🟡	🟨	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟨	🟨

Appendix G

Table A7. Monthly risk index levels for Vanuatu area councils throughout the year of 2022. Risk index levels are categorised into five severity classes: Extreme (0.81–1.00) 🟥, Severe (0.61–0.80) 🟧, Moderate (0.41–0.60) 🟠, Mild (0.21–0.40) 🟡, and Very Mild (0.01–0.20) 🟨.

Area Council	**Monthly Hazard Index Level 2022**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Aneityum	🟨	🟡	🟨	🟡	🟨	🟨	🟨	🟨	🟨	🟨	🟡	🟡
Aniwa	🟡	🟠	🟠	🟠	🟡	🟠	🟠	🟠	🟠	🟡	🟠	🟠
Canal–Fanafo	🟠	🟠	🟠	🟡	🟠	🟠	🟠	🟡	🟠	🟠	🟠	🟠
Central Malekula	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟡	🟠	🟠	🟠	🟠
Central Pentecost 1	🟠	🟡	🟡	🟡	🟡	🟨	🟡	🟨	🟡	🟡	🟡	🟡
Central Pentecost 2	🟠	🟠	🟠	🟡	🟡	🟡	🟡	🟨	🟡	🟠	🟡	🟡
East Ambae	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟡	🟨	🟡
East Malo	🟠	🟡	🟡	🟡	🟠	🟡	🟠	🟡	🟠	🟠	🟡	🟡
East Santo	🟠	🟠	🟨	🟡	🟡	🟡	🟡	🟡	🟡	🟠	🟡	🟡
Emau	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟡	🟠	🟧
Erakor	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟠	🟠
Eratap	🟠	🟡	🟠	🟠	🟠	🟠	🟠	🟠	🟡	🟨	🟠	🟠
Eton	🟠	🟨	🟡	🟠	🟠	🟠	🟠	🟠	🟡	🟨	🟠	🟠
Futuna	🟨	🟡	🟠	🟠	🟨	🟡	🟡	🟡	🟡	🟨	🟡	🟠
Gaua	🟠	🟡	🟡	🟡	🟠	🟡	🟠	🟡	🟡	🟠	🟡	🟡
Ifira	🟠	🟡	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟡	🟧	🟧
Luganville	🟠	🟡	🟡	🟡	🟠	🟡	🟠	🟡	🟠	🟠	🟡	🟡
Makimae	🟧	🟧	🟧	🟧	🟧	🟠	🟧	🟠	🟠	🟠	🟧	🟧
Malorua	🟠	🟡	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟡	🟠	🟠
Mele	🟠	🟡	🟠	🟠	🟧	🟠	🟧	🟠	🟠	🟨	🟧	🟧
Merelava	🟠	🟡	🟡	🟠	🟠	🟡	🟠	🟡	🟡	🟠	🟡	🟡
Middle Bush Tanna	🟨	🟡	🟡	🟡	🟨	🟡	🟨	🟨	🟡	🟨	🟡	🟡
Mota	🟠	🟡	🟠	🟡	🟠	🟡	🟠	🟡	🟠	🟠	🟡	🟡
Motalava	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟡	🟠
Nguna	🟠	🟡	🟠	🟠	🟠	🟡	🟠	🟡	🟡	🟨	🟠	🟠
North Ambae	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟡
North Ambrym	🟠	🟠	🟠	🟠	🟠	🟡	🟠	🟡	🟠	🟠	🟠	🟠
North East Malekula	🟠	🟠	🟠	🟡	🟠	🟠	🟠	🟡	🟠	🟠	🟠	🟠
North Efate	🟡	🟨	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟠
North Erromango	🟡	🟨	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟡
North Maewo	🟠	🟡	🟡	🟡	🟠	🟡	🟡	🟡	🟡	🟠	🟡	🟡
North Pentecost	🟠	🟡	🟡	🟡	🟡	🟨	🟡	🟨	🟡	🟡	🟡	🟡
North Santo	🟡	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟡	🟨	🟡
North Tanna	🟨	🟡	🟡	🟡	🟡	🟡	🟨	🟨	🟡	🟨	🟡	🟡
North Tongoa	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟡	🟠	🟠	🟠	🟠
North West Malekula	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟡
North West Santo	🟡	🟨	🟡	🟨	🟡	🟡	🟡	🟨	🟨	🟡	🟡	🟡
Paama	🟠	🟠	🟠	🟠	🟡	🟡	🟠	🟨	🟠	🟠	🟠	🟠
Pango	🟠	🟡	🟠	🟠	🟧	🟠	🟧	🟠	🟠	🟡	🟧	🟧
Port Vila	🟠	🟡	🟠	🟠	🟧	🟧	🟧	🟧	🟠	🟨	🟧	🟧
South Ambae	🟠	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟡	🟡	🟡	🟡
Southeast Ambrym	🟠	🟠	🟠	🟠	🟡	🟡	🟠	🟨	🟠	🟠	🟠	🟠
Southeast Malekula	🟧	🟧	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟠
Southeast Santo	🟠	🟠	🟡	🟡	🟠	🟡	🟡	🟡	🟠	🟠	🟡	🟡
South Epi	🟠	🟠	🟠	🟠	🟡	🟡	🟡	🟡	🟡	🟡	🟠	🟠
South Erromango	🟨	🟨	🟡	🟡	🟡	🟡	🟡	🟡	🟡	🟨	🟨	🟡

Table A7. *Cont.*

Area Council	**Monthly Hazard Index Level 2022**											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
South Maewo	🟥	🟧	🟧	🟧	🟥	🟧	🟧	🟧	🟧	🟥	🟧	🟧
South Malekula	🟥	🟥	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧
South Pentecost	🟥	🟥	🟥	🟥	🟧	🟧	🟥	🟧	🟥	🟥	🟥	🟥
South Santo	🟥	🟧	🟨	🟨	🟥	🟧	🟥	🟨	🟧	🟥	🟧	🟧
South Tanna	🟧	🟧	🟧	🟧	🟨	🟧	🟨	🟨	🟧	🟧	🟧	🟧
South West Malekula	🟥	🟥	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥
South West Tanna	🟨	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟧	🟧	🟧	🟧
Tongariki	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟥	🟥	🟥
Torres	🟥	🟨	🟧	🟧	🟥	🟧	🟥	🟧	🟧	🟥	🟧	🟧
Ureparapara	🟥	🟧	🟧	🟧	🟧	🟧	🟥	🟨	🟧	🟥	🟧	🟧
Vanua Lava	🟥	🟧	🟧	🟧	🟥	🟧	🟥	🟧	🟧	🟥	🟧	🟧
Varisu	🟥	🟥	🟥	🟥	🟧	🟧	🟧	🟨	🟧	🟧	🟥	🟥
Vermali	🟥	🟥	🟧	🟧	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟧
Vermaul	🟥	🟥	🟥	🟥	🟧	🟧	🟧	🟧	🟧	🟧	🟥	🟥
West Ambae	🟥	🟥	🟥	🟧	🟥	🟧	🟧	🟧	🟧	🟥	🟧	🟧
West Ambrym	🟥	🟥	🟥	🟥	🟥	🟧	🟥	🟧	🟥	🟥	🟥	🟥
West Malo	🟥	🟧	🟨	🟧	🟧	🟧	🟧	🟨	🟧	🟥	🟧	🟧
West Santo	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟨	🟧	🟧	🟧	🟧
West Tanna	🟨	🟧	🟧	🟧	🟧	🟧	🟨	🟨	🟧	🟨	🟧	🟧
Whitesands	🟧	🟧	🟧	🟧	🟨	🟧	🟨	🟨	🟧	🟧	🟧	🟥

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