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Climate Change Vulnerability and Risk of the Marine Small-Scale Fisheries Livelihoods in Sri Lanka

Senevirathne M. M. S. C.*, De Silva D. A. M. and Esham M.
Department of Agribusiness Management, Faculty of Agricultural Sciences, Sabaragamuwa University of Sri Lanka, Belihuloya 70140, Sri Lanka

Abstract

The Marine Small-Scale Fisheries (MSSF) sector in Sri Lanka contributes significantly to the income of coastal communities and to the country's food and nutrition security. However, the MSSF communities are facing challenges due to climate change, making the sector even more vulnerable. Hence, this study intended to assess the vulnerability and risks of MSSF communities associated with climate change. Primary data were collected through a survey, while data on climate-hazard variables were obtained from the Department of Meteorology. The study included 384 fishers and 60 fish processors from Tangalle, Galle, Negombo, Kalpitya, Jaffna, and Trincomalee. The vulnerability and risks indices were calculated by employing the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5) framework. The results showed that vulnerability and risks vary across different areas, but all areas exhibit a high level of vulnerability. Among the fishers, those in the Tangalle area were highly vulnerable and at risk. Further, the fish processors in Negombo were found to be the most vulnerable, while those in Galle were found to be the most at risk. Overall, communities with high sensitivity and high exposure were constrained by limited adaptability, mainly due to high dependence on fisheries activities, low levels of climate literacy, limited financial management, low-income diversification, and limited financial support. The study underscores the need to reduce sensitivity and exposure while enhancing adaptive capacity, mainly by introducing innovative financial solutions and climate-resilient infrastructure, promoting income diversification, and introducing localised community-driven adoption mechanisms to address the sector-specific vulnerabilities of the MSSF communities.

Keywords: Vulnerability, marine small-scale fisheries, climate change, livelihoods

Introduction

The Marine Small Scale fisheries (MSSF) sector offers significant benefits to Sri Lanka's economic growth and stability by providing livelihoods to coastal communities and ensuring food and nutritional security in the country (Ibrahim, 2020). Despite its significance, the MSSF sector in Sri Lanka is associated with devastating challenges, such as declining incomes, increasing costs, stock depletion, exploitation by intermediaries, and poor market linkages (Karmakar, Mehta, Ghosh, & Selvaraj, 2009; De Alwis, 2024).

These issues are further exacerbated by climate change, creating multiple vulnerabilities for MSSF communities, particularly in developing countries with less adaptive capacity to cope with its effects (Selvaraj, Guerrero, Cifuentes-Ossa, & Alvis, 2022). According to Villasante et al. (2022), climate change poses unprecedented adverse effects, including rising sea temperatures, ocean acidification, changing rainfall patterns, altered ecosystems, reduced fish availability, and disruptions to fishing activities. The Sri Lankan marine fisheries sector is primarily affected by sea-level rise. Sea level rise creates diverse impacts on fishing livelihoods, such as coastal flooding and flash floods (Nianthi & Shaw, 2015; Arulananthan, 2016). According to the Ministry of Environment, Sri Lanka (2022), climate change is causing shifts in the geographic range and timing of biological events (maturity, reproduction,

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**Email: sulochana@agri.sab.ac.lk*

etc.), altering growth rates and productivity, increasing disease susceptibility, and disrupting entire aquatic ecosystems.

According to the AR6 Synthesis Report (Calvin et al., 2023), vulnerability is defined as "the propensity or predisposition to be adversely affected". Vulnerability assessment (VA) is the process of assessing and characterising a system's exposure, sensitivity, and adaptive capacity to climate change (Dessai & Hulme, 2004). VA provides a better understanding of the multitude of interaction constraints among systems, pressures, and threats, which serves as a basis for targeted adaptation strategies (Mamauag et al., 2013; Chen, López-Carr, & Walker, 2014). Most previous studies have focused on the ecosystem vulnerability of fishing or coastal communities to climate change (Johnson & Welch, 2009; Mamauag et al., 2013). A handful of studies investigate the vulnerability of fishing communities and how they cope with and respond to change (Chen et al., 2014). Nevertheless, available information on how local fishery-based livelihood systems are vulnerable to climate change, especially in developing countries, is very limited (Huynh, Le, Le, & Nguyen, 2021). Climate change impacts on the fisheries sector in Sri Lanka have received relatively little attention (Ministry of Environment, Sri Lanka, 2022). Understanding the vulnerability of the fishing communities is essential for identifying actions that can mitigate adverse impacts (Islam, Sallu, Hubacek, & Paavola, 2021). Despite its importance, knowledge of vulnerability and risk levels at the local scale of small-scale fishery-based livelihoods remains limited. Most prior studies have assessed Sri Lanka's climate change vulnerabilities at the national or sectoral level (Ministry of Mahaweli Development and Environment, Sri Lanka, 2016; Ministry of Environment, Sri Lanka, 2022; World Bank Group and Asian Development Bank, 2021), not specifically those of Small-Scale Fisheries Communities. There are a few localised studies in Sri Lanka, which are largely descriptive and site-specific (Azmi, 2021; Galappaththi, Ford, Bennett, & Berkes, 2021). Moreover, there is low capacity and high vulnerability to climate change among upstream nodes in the value chain, such as fishers and fish processors in Sri Lanka (Esham & Wijeratne, 2021). Given its importance, the present study comprehensively assesses climate change vulnerability and evaluates

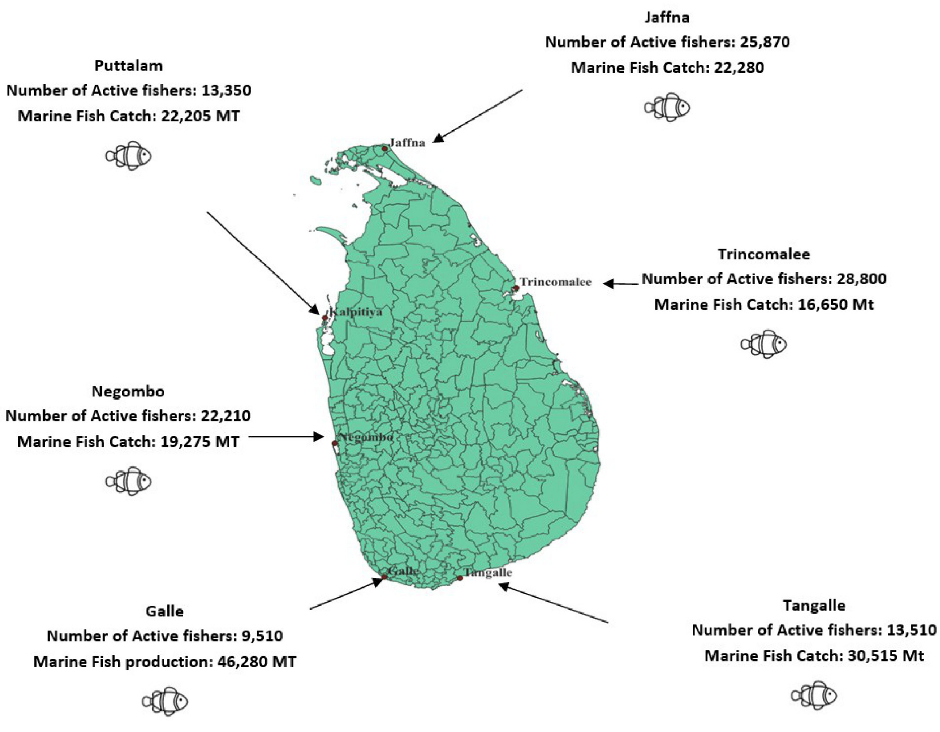


Fig. 1. Data collection locations with the active number of fishers and marine fish catch in the year 2023 (Ministry of Fisheries, Aquatic and Ocean Resources, Sri Lanka, 2024)

its climate risk among MSSF communities (fishers and fish processors) in Sri Lanka using the IPCC AR5 framework.

Materials and Methods

The study assessed vulnerability to climate change among MSSF communities in major fishing areas across Sri Lanka's Southern, Northern, Northwestern, and Eastern Coastal Belts (Fig. 1). The data were collected through surveys from the MSSF communities (upstream value chain actors; fishermen and fish processors) in Galle, Tangalle, Negombo, Kalpitya, Trincomalee, and Jaffna. The sample comprises 324 purposively selected marine small-scale fishers (representing all study locations) and 60 small-scale fish processors (representing Galle, Tangalle, and Negombo). Purposive sampling was used in order to select the respondents who were directly involved in small-scale fishing and fish processing, as a comprehensive sampling frame was not available.

The study employed a composite index approach to calculate vulnerability, guided by the risk assessment framework outlined in the IPCC AR5. Table 1 shows the variables used to calculate each dimension. The hazard dimension reflects the level of climatic stressors over time affecting small-scale fishers and fish processors.

According to the IPCC's AR5 synthesis report, a climate vulnerability index is typically derived by combining, with or without weighting, several indicators assumed to represent vulnerability. In this study, each indicator was given equal weighting, as adopted in most previous studies (Hahn, Riederer, & Foster, 2009; Islam et al., 2014; Huynh et al., 2021), due to the absence of a robust weighting method available for the region. All indices were first transformed to a scale for the sensitivity, exposure, adaptive capacity, and hazard dimensions. Furthermore, one limitation of this study was that hazard indicators were treated as region-specific constants, assuming that all the individuals within a region experience the same level of hazard over time. Due to data limitations, the hazard indicators were taken for relatively short periods (8–10 years), which may not fully reflect the climate change variability.

For hazard, sensitivity, and exposure indicators, the values were categorised into levels (e.g., 0 = least severe, 4 = most severe). For adaptive capacity, 4 indicates the highest adaptive capacity level, and 0 indicates the lowest. To enable comparability among the scores, all scores were then rescaled to 0–1 by dividing by 4. Normalisation was performed using the following equation:

$$Normalized\ value = \left(\frac{Value}{4}\right)$$

After normalisation, the subcomponents for each area were averaged for each region, and the indices for each subcomponent was summed to create the index for each main component. Then, the following equation was used to calculate each respondent's vulnerability index (Antwi-Agyei, Fraser, Dougill, Stringer, & Simelton, 2012; Cinner et al., 2012).

$$Vulnerability = (Exosure + Sensitivity) - Adaptive\ Capcity$$

Risk was calculated using the following equation:

$$Risk = Hazard * Vulnerability$$

Results and Discussion

Table 2 presents the socio-demographic profile of the surveyed respondents. According to the results, the average age of fishers was 49 years, and they participated in fisheries activities on an average of 18 active days per month. The average household size was five members, and the average monthly expenditure was LKR 59,630. Fishers completed 9 years of formal education on average, and the average years of fishing experience was 27 years. 90% of the fishers identified as boat owners, while 10% were crew members. The average age of fish processors was 60 years, and all were female. Considering work seasonality, fish processors worked an average of 25 days per month during the season. Households averaged 4 members, and 2 of those were school-aged children. The average monthly expenditure was LKR 47,867, and respondents had completed an average of 11 years of formal education. The average experience in fish processing was 17 years. All respondents indicated that these temporal patterns have changed over the last 5–10 years.

Considering the fishing seasons, they were closely tied to the bimodal monsoon. In the southwest coastal area (including Tangalle, Galle, Negombo, and Kalpitiya), the peak fishing and fish-processing seasons occur from January to April, while the lowest fish processing activity occurs from May to July due to the southwest monsoon. The northeast

Table 1. Vulnerability and Risk Indices calculating variables

Dimension	Variable used for scoring	Scoring classification
Hazard	Number of heavy winds/cyclones in the past 8 years (annual count of fisheries advisories "very rough" or "rough" sea conditions	0 = Low: ≤20, 1 = Moderate: 21–25, 2 = High: 26–30, 3 = Very high: 31–35, 4 = Extreme: >35
	Maximum Temperature (Mean of the average monthly maximum temperature for the past 10 years in ºC)	For fishers, 0 = Lower heat: <30.0 ºC, 1 = Warm: 30.0–30.99 ºC, 2 = Hot: 31.0–31.99 ºC, 3 = Very hot: 32.0–33.49 ºC, 4 = Extreme heat: ≥ 33.5 ºC
		For fish processors: 0 = Optimal drying conditions: 30.0–33.0 °C, 1 = Mild stress (slightly low or slightly high): 27.0–29.9 °C or 33.1–34.9 °C, 2 = Moderate risk: 25.0–26.9 °C or 35.0–36.9 °C, 3 = High risk: < 25.0 °C or 37.0–38.9 °C, 4 = Extreme risk: ≥39.0 °C or prolonged heat-induced spoilage risk
	Minimum Temperature (Mean of average monthly minimum temperature for the past 10 years in ºC)	For fishers, 0 = Cool nights: <24.0 ºC, 1 = Warm nights: 24.0–24.99 ºC, 2 = Hot nights: 25.0–25.99 ºC, 3 = Very hot nights: 26.0–27.49 ºC, 4 = Extreme hot nights: ≥ 27.5 ºC For fish processors, 0 = Optimal condition: < 23.0 °C, 1 = Mild risk: 23.0–24.9 °C, 2 = Moderate risk: 25.0–26.9 °C, 3 = High risk: 27.0–28.9 °C,4 = Extreme risk: ≥ 29.0 °C
	Rainfall (Mean of monthly avg. of the past 10 years)	0 = Very low rainfall: 0- 50 mm, 1= Fairly Heavy rain: 51 -100 mm, 2 = Heavy rain: 101 – 150 mm, 3= very heavy rain: 151 -200 mm, 4= extreme heavy rain: 201mm or more
Exposure	Historical hazard impact frequency: Damage to fishing assets (vessels, nets, landing sites, etc.) (only for fishers)	0 = No incidents, 1= <1 week downtime or < 5% replacement cost, 2 = 1–4 weeks or 5–20% cost, 3 =>4 weeks or >20%-40% cost or total loss/forced displacement, 4= > 8 weeks downtime or > 40% cost, total loss, or forced displacement
	Average number of longest fishing days, fish processing days lost per month (frequency of disruption)	0 = 0–2 days, 1 = 3–5 days, 2 = 6–10 days, 3 = 11–15 days, 4 = >15 days
	Most extended consecutive climate-related shutdown (days, last year- off-season (continuity of disruption)	0 = 0 -1 days, 1 = 2–6 days, 2 = 7–10 days, 3 = 11–15 days, 4 = > 15 days
	Type of fishing craft used	4 = Outboard Motor FRP Boats – OFRP, 3 = Motorized Traditional Boats – MTRB, 2= Non-motorized Traditional Boats – NTRB, 1= Non-motorized Traditional Beach-seine Boats – NBSB
	Proximity of the boat location to safe landing sites/harbour / Location of the processing yards	0 = <500 m, 1 = 500 m–1 km, 2 = 1–2 km, 3 = > 2 km, 4 = No access.
	Distance from the coastline	
Sensitivity	Fishing or processing effort (Number of days a household is involved with fisheries in the last year)	0 = 0–60, 1 = 61–120, 2 = 121–180, 3 = 181–240, 4 = > 240
	% income from fisheries	0 = 0–20%, 1 = 21–40%, 2 = 41–60%, 3 = 61–80%, 4 = >80%
	Number of school-aged children	0 = 0, 1 = 1, 2 = 2, 3 = 3, 4 = ≥4
	Type of drying surface (fish processors only)	0 = Covered/solar tunnel, 1 = Raised racks, 2 = Concrete slab, 3 = Plastic/tarpaulin/ ground, 4 = Bare ground
	Cold chain dependency gap fish processors only)	0 = Integrated cold chain, 1 = Reliable ice/freezer, 2 = Shared/limited, 3 = Occasional access, 4 = No access

Adaptive Capacity	Adult workforce: Number of individuals aged 14–60 in household	0 = 0–1, 1 = 2–3, 2 = 4–5, 3 = 6–7, 4 = ≥ 8
	Experience of fisheries-related activities (years)	0 = 0–1, 1 = 2–5, 2 = 6–10, 3 = 11–20, 4 = > 20
	The highest years of schooling	0 = 0–2, 1 = 3–5, 2 = 6–8, 3 = 9–11, 4 = ≥ 12
	Income Diversification: Number of income-generating activities	0 = 0, 1 = 1, 2 = 2, 3 = 3, 4 = ≥ 4
	Access to credit/insurance/or any social security scheme	0= No support, 1= Informal support only, 2= Informal + occasional formal access, 3= Regular access to formal support, 4= Multiple formal mechanisms
	Membership in fisheries cooperatives or associations	0= Not a member of any fisheries cooperative/association, 1= Informally connected with other fishers (no formal membership), 2= Member of a cooperative but inactive, 3= Active member of cooperative/association with occasional participation, 4= Active member with leadership roles or participation in multiple associations
	Adaptive Behavior	0 = Never heard about climate change, 1 = Heard but cannot explain impacts, 2 = Aware of impacts and few practices, rarely implements, 3 = Understands impacts and applies some adaptive actions, 4 = Fully aware, implements multiple strategies, and shares knowledge
	Presence of protective structure (e.g., sea wall)	0= No protective structure, 1= presence of protective structure

monsoon brings rain to the northeast coast (Jaffna and Trincomalee), typically from October to February. This monsoon is associated with strong winds and rough seas, which adversely affect fishing activities. Therefore, on the north and east coasts, fishing activities were best from March to September. All respondents indicated that these temporal lines have changed over the past few decades, increasing vulnerability. Fishers are mainly affected by rough sea conditions resulting from high wind speeds and wave heights, while fish processors are primarily affected by rainfall, especially irregular and unpredictable rainfall.

Fig. 2. shows the climate descriptors by site: the mean and Standard Deviation (SD) of the annual number of coastal weather warnings and advisories, monthly maximum and minimum temperatures, and monthly rainfall (mm). Coastal weather warnings and advisories were issued by the Marine Meteorological Division of the Department of Meteorology and were extracted from the Disaster Management Centre Website for the period 2018–2025. The advisories or warnings were primarily issued in response to sea-level rise and strong winds, which led to rough or very rough sea conditions. We excluded the warnings/advisories issued for the multi-day boats, ensuring that the counts accurately reflect the conditions of small-scale fishers. Kalpitiya recorded the highest frequency (262), followed by Tangalle (238), Negombo (206), Galle (204), Jaffna (176), and Trincomalee (152). The analysis indicated that the number of "warnings" (red alerts) has increased over time, with 2025 recording the highest number to date. The results also indicate that the frequency of hazardous events and sea conditions varies substantially over the years and tends to concentrate in specific zones, particularly in the north-western and southern regions.

Considering the rainfall data, data were available for all areas. However, temperature data for Galle were used as a proxy for Tangalle, and data from Katunayake station were used as a proxy for both Negombo and Kalpitiya. The mean (± SD) of monthly maximum temperature in Galle/Tangalle was 30.03 ± 0.97 °C. In Negombo/Kalpitiya (Katunayake), it was 31.66 ± 1.06 °C, 31.75 ± 1.73 °C in Jaffna, and 32.60 ± 2.39 °C in Trincomalee. The mean (±SD) monthly minimum temperature in Galle/Tangalle was 25.27 ± 0.89 °C. In Negombo/Kalpitiya, the values were 24.43 ± 1.27 °C and 25.21 ± 2.18 °C in Jaffna, and 24.91 ± 1.03 °C in Trincomalee. Corresponding monthly rainfall (mean ± SD, mm) was 219.09 ± 160.98 in Galle, 134.49 ±

Table 2. Socio-economic-demographic profile of the surveyed individuals

Group and sample size	Variable	Average Value	Trincom alee	Tangalle	Galle	Negombo	Kalpitiya	Jaffna
Fishers	Average Age (in years)	49 years	50 years	47 years	48 years	50 years	45 years	53 years
Sample size: Total: 324 54 fishers from each location	Seasonality of Work (Number of active days per month)	18 days	22 days	21 days	19 days	17 days	15 days	16 days
	Average number of members in the households	5 members	4 members	3 members	4 members	5 members	6 members	5 members
	School-aged children	2 members	3 members	2 members	2 members	2 members	3 members	2 members
	Average monthly expenditure (Rs.)	LKR 59,630	LKR 53,250	LKR 63,125	LKR 62,100	LKR 74,500	LKR 56,400	LKR 48,400
	Average years of formal education	9 years	9 years	11 years	10 years	8 years	10 years	7 years
	Experience in fishing (in years)	27 years	35 years	17 years	23 years	26 years	33 years	29 years
	Boat owners (% of respondents)	90%	88%	91%	82%	90%	92%	94%
	Crew members (% of respondents)	10%	12%	9%	18%	10%	8%	6%
Fish	Average Age	60 years	-	53 years	65 years	63 years	-	-
Processors Total =60 (20 fish processors each from Tengalle, Ambalangoda and	Seasonality of Work (Number of active months per year)	25 days	-	23 days	26 days	25days	-	-
Negombo)	Average number of members in the households	4 members	-	4 members	4 members	5 members	-	-

School-aged children	2 members	-	1 member	2 members	3 members	-	-
Average monthly expenditure (Rs.)	LKR 47,867	-	LKR 54,000	LKR 43,500	LKR 46,100	-	-
Average formal year of education	11 years	-	11 years	11 years	10 years	-	-
Experience in fish processing (in years)	17 years	-	21 years	17 years	14 years	-	-
Male/ Female	100 % female	-	100 % female	100 % female	100 % female	-	-

Source: Field survey 2024

122.16 in Tangalle, 163.62 ± 158.60 in Negombo, 87.61 ± 149.09 in Kalpitiya, 125.83 ± 175.61 in Jaffna, and 144.1 ± 162.82 in Trincomalee.

Table 3 displays the level indicators, categorised as low, medium, high, and very high, to provide a clear understanding of each factor's contribution to the vulnerability and risk of the fishers and fish processors. According to Table 3, the main contributing factors to increased vulnerability were high fishing effort, the percentage of income derived from fishing (high dependence), and extended shutdown periods caused by climate change. Moreover, adaptive capacity was primarily diminished by low income diversification, limited access to finance, low membership levels in fisheries organisations, and a lack of adaptive behaviour. Among fish processors, the main factors contributing to vulnerability were the lack of storage/cold chain facilities and the frequent loss of fishing days due to climate events.

Subsequent sections explain each indicator in detail using the calculated values. Considering the fishers, this section explains the hazards, exposure, sensitivity, adaptive capacity, vulnerability, and risk levels.

Based on the parameters in Table 1, the hazard level was calculated. Galle recorded the highest hazard index (0.56) among the study areas, mainly due to frequent, high-intensity rainfall events and the high frequency of weather warnings and advisories issued over time. On the other hand, Negombo, Kalpitiya, and Jaffna areas recorded hazard indices of 0.44. Considering the exposure levels, the results of this study indicate that the exposure was highest among fishers in Kalpitya (0.687), followed by Jaffna (0.615), Trincomalee (0.613), Tangalle (0.550), Galle (0.490), and Negombo (0.480). Kalpitya's high exposure was mainly due to prolonged fishing shutdowns (0.983), the highest frequency of disruptions (0.817), and damage to the fishing infrastructure from climate events (0.833). Trincomalee also recorded high exposure, mainly driven by limited access to safe landing sites (0.813), where only large boats were berthed in harbours while small boats were beach-moored. On the other hand, Kudawella, Galle, and Negombo areas have better access to harbours or safe landing sites. In Galle, long closure periods were observed (0.850); however, a moderate number of days were lost (0.533). Given the types of fishing craft used, many study locations rely on motorised traditional boats and outboard-motor FRP boats, which are highly vulnerable to extreme weather events. In contrast, in Jaffna, the number of non-motorised traditional boats and traditional beach seine boats was higher than in other locations. In terms of fishing craft, all areas exhibited high exposure due to the fishing vessels, which were vulnerable to extreme climatic events.

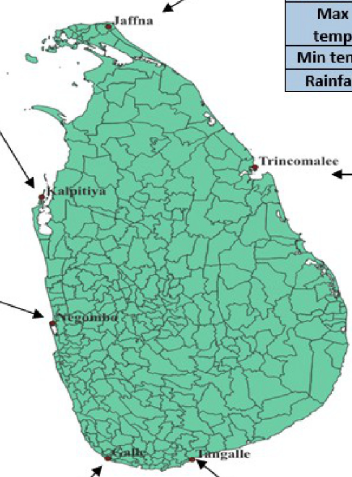
Sensitivity was high across all six sites: Galle, 0.722; Trincomalee, 0.721; Tangalle, 0.713; Jaffna, 0.700; Negombo, 0.683; and Kalpitiya, 0.644. All areas report a high degree of dependence on fisheries for their livelihood. The slightly higher value for Trincomalee can be attributed to its significant dependence on income from fisheries activities (0.950). Tangalle recorded marginally lower sensitivity due to its moderately lower share of fisheries

Jaffna

	Mean	S.D
Weather advisory /warnings	22.5	8
Max temp	31.75	1.73
Min temp	25.21	2.18
Rainfall	124.85	175.61

Kalpitiya

	Mean	S.D
Weather advisory /warnings	32	9
Max temp	31.66	1.06
Min temp	24.43	1.27
Rainfall	87.6	149.09



Trincomalee

	Mean	S.D
Weather advisory /warnings	19	12
Max temp	32.60	2.39
Min temp	24.91	1.03
Rainfall	144.1	162.82

Negombo

	Mean	S.D
Weather advisory /warnings	24.5	9
Max temp	31.66	1.06
Min temp	24.43	1.27
Rainfall	163.6	158.60

Galle

	Mean	S.D
Weather advisory /warnings	25.5	7
Max temp	30.03	0.97
Min temp	25.27	0.89
Rainfall (mm)	219.1	160.98

Tangalle

	Mean	S.D
Weather advisory /warnings	31.5	8
Max temp	30.03	0.97
Min temp	25.27	0.89
Rainfall	134.5	122.16

Fig. 2. Climatic descriptors by site (Source: Department of Meteorology, Sri Lanka)

*Note: Weather advisories and warnings: restricted to the events categorised as "very rough" (Wind Speed 56-74 km/h and 4-6 m wave height) and "rough" (Wind speed 47-55 km/h and 3-4 m wave height).

income within household income (0.944) and a lower proportion of school-aged children (0.208), despite the high number of fishing days (0.986). Kalpitiya had the lowest sensitivity score (0.644) among the study areas, mainly due to the lowest fishing effort (0.617). Their average fishing days were 154 per year, and the % contribution to household income was relatively lower compared to other areas (0.817).

According to the results, the adaptive capacity was relatively low compared to exposure and sensitivity levels. Adaptive capacity was highest in Galle (0.465), followed by Trincomalee (0.434), Kalpitya (0.402), Jaffna (0.402), Negombo (0.342), and lowest in Tangalle (0.313). Fishing families of Galle have a comparatively larger adult workforce (0.542), a higher level of education (0.658), moderate access to finance (0.483), and exhibit relatively stronger adaptive behaviour (0.342), along with moderate experience (0.750) and moderate cooperative membership (0.383). Trincomalee ranks second in adaptive capacity, boosted by longer years of experience in fisheries (0.888) and a high level of membership in fisheries cooperatives/organisations (0.588); however, it is constrained by limited income diversification, sole reliance on fisheries activities, and low adaptive behaviour (0.150). Tangalle lags mainly due to a smaller adult workforce (0.264), limited access to finance (0.278), weak membership (0.167), and very low adaptive behaviour (0.042); its relatively good level of education (0.694) cannot offset these deficits. Income diversification was low across all areas, which suppresses adaptive capacity. Kalpityia fishers reported the highest adaptive capacity, which was still at a moderate level (0.431). Fishers in Kaplitya were engaged in several additional income-generating activities, such as labour work, boat riding, and running grocery shops.

Fig. 3 shows the vulnerability and risk triangle diagram of the contributing factors of vulnerability

Table 3. Level of contributing factors for each indicator

Indicators	Trincomalee	Galle	Tangalle	Negombo	Kalpitya	Jaffna
Marine Small-Scale Fishers						
Hazard history	M	M	H	M	VH	M
Average fishing days lost per month	H	H	H	H	VH	H
Longest fishing days lost	VH	VH	VH	VH	VH	H
Type of fishing craft used	H	H	H	H	H	H
Access to a harbour/ safe landing site	VH	L	L	L	M	VH
Fishing effort	VH	VH	VH	VH	M	VH
% income from fisheries	VH	VH	VH	VH	VH	VH
Number of school-aged children	L	M	L	L	H	L
Adult workforce	M	H	M	H	H	M
Experience in fisheries	VH	VH	H	VH	H	VH
Education level	H	H	H	H	H	M
Income diversification	L	L	L	L	L	L
Access to finance	M	M	M	M	M	M
Membership in fisheries cooperatives/ associations	H	M	L	M	M	M
Adaptive behavior	L	M	L	M	M	L
Marine Small-Scale Fish Processors						
Average fish processing days lost per month	-	H	H	H	-	-
Longest fish processing days lost per month	-	VH	VH	VH	-	-
Distance to shoreline	-	H	M	VH	-	-
Active days of fish processing	-	VH	VH	VH	-	-
% income from fish processing	-	M	M	M	-	-
Number of school-aged children	-	M	H	H	-	-
Type of drying surface	-	M	M	VH	-	-
Cold chain dependency gap	-	VH	VH	VH	-	-
Adult workforce	-	M	M	M	-	-
Experience in processing	-	H	H	H	-	-
Education level	-	VH	VH	H	-	-
Income Diversification	-	L	L	L	-	-
Access to finance	-	H	H	H	-	-
Membership in fisheries cooperatives/ associations	-	H	H	M	-	-
Adaptive behavior	-	H	H	M	-	-
Presence of protective sea wall structure	-	M	L	L	-	-

and Risk. Based on the results, Tangalle was identified as the most vulnerable area among small-scale fishers. Tangalle recorded the highest vulnerability (0.65) and risk (0.475), mainly due to lower adaptivity relative to high exposure and sensitivity levels. The vulnerability of the fishers in Jaffna was also high (0.64), although the risk level was moderate (0.402). Trincomalee exhibited high vulnerability (0.63), but a relatively lower risk (0.342), combined with a lower hazard level (0.38). Kalpitya recorded a vulnerability of 0.63 and a risk of 0.364. Galle recorded a moderate vulnerability level (0.747) but the highest hazard level (0.56), resulting in a risk of up to 0.418. Negombo was the least vulnerable (0.713), recording the lowest risk (0.314).

Considering the fish processors, this section explains the hazards, exposure, sensitivity, adaptive capacity, vulnerability, and risk levels.

For hazard levels, fish processors in Galle recorded the highest value (0.45), mainly due to the frequent and intense rainfall events, followed by Tangalle (0.395) and Negombo (0.33). The highest exposure value was reported for Negombo (0.806), followed by Galle (0.713) and Tangalle (0.650). The high exposure in Negombo was mainly due to the proximity of processing yards to the shoreline (0.983). In Negombo, drying activities occurred at a larger scale near the shoreline, increasing vulnerability to sudden weather changes (e.g., heavy rainfall, coastal flooding, storms, and inundation). Moreover, the average number of fishing days lost per month and the shutdown periods were also high in Negombo. Across all areas, fish processors lost significant working days due to climate events. Considering the sensitivity, the Negombo fish processors recorded the highest value (0.680), followed by Galle (0.607) and Tangalle (0.577). Negombo's high sensitivity was mainly due to the prevalence of open mat drying (0.800). Compared to other areas, Galle records the highest dependency on fish processing activities as a source of income (0.967). Tangalle records the lowest sensitivity (0.577) due to the use of less climate-vulnerable rack-based drying (0.283) and a comparatively lower number of days involved in fish processing activities than other locations (0.800).

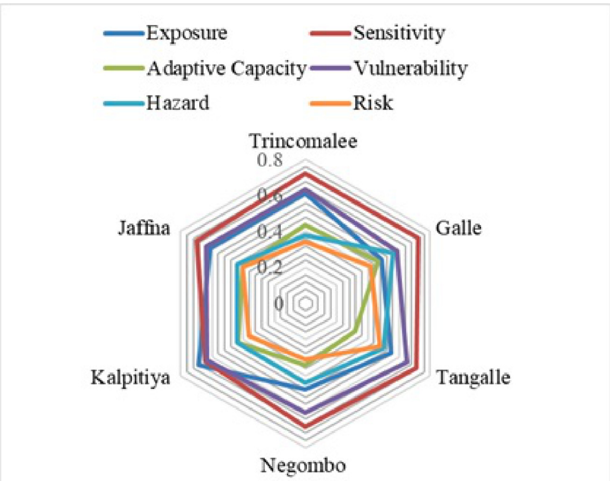


Fig. 3. Vulnerability and risk triangle diagram of the contributing factors of vulnerability and risk

Notably, across all three areas, the cold chain/storage facilities (Galle: 0.883, Negombo: 0.833, and Tangalle: 0.817) were a dominant driver of increased sensitivity. Due to insufficient cold storage facilities, fish processors were unable to preserve surplus during off-seasons, forcing rapid sales during peak seasons at lower prices.

In terms of adaptive capacity, fish processors of Tangalle showed the highest score (0.496), although this remained at a moderate level, followed by Galle (0.463) and Negombo (0.419). Moreover, Fish processors in Tangalle had relatively longer years of experience in fish processing (0.633), active membership in fisheries cooperatives or organizations (0.650), and better adaptive behaviour/knowledge in climate change (0.617), supported by effective access to finance (0.633), mainly derived via informal sources, village-level bank institutions such as "SANASA", and regional development banks. Compared to the other two areas, women's community groups in Tangalle were more active and offered a range of financial opportunities, including savings, loan facilities (both individual and group), and other financial support services. Moreover, income diversification was comparatively higher, with many engaged in multiple businesses, helping them manage livelihoods during the off-seasons. Galle ranked second in adaptive capacity (0.463), mainly derived from the highest education levels (0.800), but was constrained by weak income diversification (0.117) and limited protective infrastructure (0.267). Negombo showed a relatively larger adult workforce in households (0.433) and good access to finance, particularly through fisheries NGO-driven banking systems such as "Sri Vimukthi". However, its adaptive capacity remained low primarily due to lower educational levels (0.517) and very low-income diversification (0.067) compared to other areas.

The vulnerability index values for fish processors were 0.689 for Negombo, 0.620 for Galle, and 0.577 for Tangalle. Negombo exhibited the highest vulnerability due to high exposure (0.806) and sensitivity score (0.680), combined with low adaptive capacity (0.419. The Tangalle fish processors recorded a lower vulnerability value than other fish processors, reflecting moderate exposure (0.650) and sensitivity (0.577), balanced by a higher adaptive capacity (0.496).

In conclusion, this study provides a clear understanding of how vulnerabilities and risks vary across

MSSF communities across different regions. The warnings and advisories issued to fishing communities regarding extreme sea conditions have increased over time. Some areas exhibited low vulnerability but high hazard levels, resulting in elevated risk. Overall, communities with high sensitivity and exposure were constrained by limited adaptability, resulting in high vulnerability and risk. The study has critical implications for the fishery and adaptation planning. It underscores the need to reduce sensitivity and exposure while enhancing the adaptive capacity through climate-responsive fishing policies and regional specific adaptation planning. The practical strategies includes providing financial and climate change adaptation support programs, developing climate resilient infrastructures (fishing vessels, storage facilities and drying racks), promoting income diversification by enhancing knowledge and skills for alternative livelihood opportunities, introducing innovative financial tools (e.g., parametric insurance schemes, savings clubs, impact investment, etc.), implementing localised community-driven adoption mechanisms, and strengthening community-level associations/cooperatives and institutional support to address the sector-specific vulnerabilities of MSSF communities.

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