

Vulnerability of Seaweed Farmers and Adaptation to Climate Change on Pemba Island, Zanzibar.

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abstract

Climate change poses significant threats to coastal livelihoods in small islands, particularly, in sub-Saharan Africa, where communities such as seaweed farmers on Pemba Island, Zanzibar, face heightened vulnerability. This study assessed the vulnerability and adaptation of seaweed farmers to climate change in Micheweni District, focusing on perceived effects, vulnerability levels, and current adaptation practices. Using a cross-sectional design, data were collected using a survey questionnaire from 183 smallholder farmers in Maziwa Ng'ombe and Kiuyu Mbuyuni Shehia. Vulnerability was measured using the IPCC-derived Livelihood Vulnerability Index (LVI), which incorporates exposure, sensitivity, and adaptive capacity based on sustainable livelihood capitals. The results highlighted that seaweed farming is female-dominated (72.7%), with low education levels (63.9% nonformal). The overall LVI was 0.27, indicating moderate vulnerability, suggesting that farmers can manage current risks, but face a potential decline in livelihoods without enhanced support. This was driven by moderate-to-high exposure (0.64), reflecting frequent hazards like rising temperatures and floods that threaten assets; high sensitivity (0.74), due to heavy natural resource dependence that amplifies disruptions in productivity and income; and low-to-moderate adaptive capacity (0.49), constrained by limited financial and physical assets, reducing options for coping or recovery. All farmers perceived negative climate impacts on seaweed growth and production, with household yields declining from 4,480 kg in 2016 to 2,422 kg in 2020, attributed to heat stress and winds. Adaptation practices identified included changing farming methods (68.9%, e.g., deep-water cultivation), crop diversification (35%), and alternative activities (39.3%, e.g., livestock), with gender differences highlighting women's focus on on-farm strategies. The findings underscore the need for context-specific interventions, such as deep-water technologies and gender-inclusive policies, within Zanzibar's Blue Economy, to build resilience and prevent poverty escalation amid climate risks. We recommend that future research evaluate the adaptation effectiveness of the new strategies.

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Introduction

Islands and coastal areas experience multiple challenges attributable to extreme weather events caused by climate change (e.g., Matoju et al., 2022; Rybråten et al., 2018). Climate change-related challenges include increasing temperature, rising sea level, destruction of aquatic life, loss of habitat and biodiversity, destruction of mangroves and coral reefs. There are other extreme weather events, such as unpredictable rainfall and irregular changes in wind speed and direction. Such climate-induced stressors directly threaten resource-dependent livelihoods, particularly in vulnerable sectors like aquaculture and fisheries, where the ecosystems are highly sensitive to environmental shifts. For instance, seaweed farming, a key coastal activity reliant on stable ocean conditions, is particularly susceptible to these changes, as rising ocean temperatures cause heat stress, reduced yields, and increased disease prevalence, while stronger winds and erratic rainfall disrupt cultivation practices and harvest stability (Bernard et al., 2024; Makame et al., 2021). These extreme weather conditions disproportionately affect the most

impoverished and vulnerable populations, exacerbating socioeconomic inequalities in regions where livelihoods are intertwined with natural resources (Ballesteros & Esteves, 2021; Matoju et al., 2022). In Zanzibar, this vulnerability is starkly evident among seaweed farmers on Pemba Island, where poverty levels remain alarming and directly linked to climate impacts on this primary income source. The World Bank report indicates that the poverty rate in Pemba increased from 48 per cent to 55 per cent between 2010 and 2015 (World Bank, 2017). Although these rates decreased from 2015 to 2019, poverty levels are still high in Pemba (Office of Chief Government Statistician (OCGS), 2020). This trend is not uncommon in small islands of developing countries, which share heightened exposure to climate change (Klöck & Nunn, 2019). Coastal fisheries and aquaculture communities in sub-Saharan Africa, including those in Zanzibar, face high socioeconomic vulnerability amid environmental pressures, as declining marine productivity undermines food security and economic stability (Yang et al., 2019). Within Pemba Island, the Micheweni District exemplifies these interconnected challenges (Bakari, 2015). Micheweni relies on diverse livelihoods such as fishing, petty trade, crop farming, and seaweed cultivation, with farming contributing over 50% to household income and food security (Integrated Food Security Phase Classification (IPC), 2017). However, seaweed production, one of the main income sources for resource-constrained households, has declined sharply due to climate pressures on the supporting ecosystem. Factors responsible for the decline include rising ocean

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temperatures leading to heat stress and lower yields, increased winds, irregular rainfall, diseases, over-utilization of shallow waters, COVID-19 disruptions, and price fluctuations (Bernard et al., 2024; Makame et al., 2021). Production fell from 16,000 tons in 2015 to below 10,000 tons in 2019 (Makame et al., 2021), directly impacting smallholder farmers' incomes in Micheweni, where poverty rates are the highest in Zanzibar: 48.1% for basic needs poverty and 18.7% for food poverty (OCGS, 2020).

Despite these evident effects, knowledge gaps persist regarding seaweed farmers' vulnerability in terms of exposure, sensitivity, and adaptive capacity, as well as their adaptation strategies (Bakari, 2015). Vulnerability varies across scales, from individuals and households to communities and regions, and across activities like aquaculture, agriculture, and fisheries (Berkes, 2007; Brugère, 2015). Effective adaptation demands context-specific approaches tailored to local knowledge and practices (Arwati et al., 2025). This study assessed the vulnerability and adaptation of seaweed farmers to climate change in Micheweni District in Pemba Island, Zanzibar. The specific objectives that guide this work are to examine the perceived effects of climate change on seaweed farming, determine vulnerability levels among seaweed farmers, and explore the current adaptation practices among the seaweed farmers.

This study contributes to the growing body of literature on climate change vulnerability in small island developing states (SIDS), particularly within sub-Saharan Africa's coastal and aquaculture sectors. The paper addresses a noted knowledge gap in localized, empirical assessments (Bakari, 2015) by applying the Intergovernmental Panel for Climate Change (IPCC) derived Livelihood Vulnerability Index (LVI) to quantify the exposure, sensitivity, and adaptive capacity among seaweed farmers. Unlike broader studies on production declines and stressors in Zanzibar (e.g., Bernard et al., 2024; Makame et al., 2021), this paper provides gender-disaggregated insights into adaptation practices, such as deep-water cultivation and diversification, highlighting women's higher engagement in on-farm strategies. The findings enhance our understanding of socioeconomic vulnerabilities in resource-dependent communities, offering practical implications for Zanzibar's blue economy policies and resilience-building in similar island contexts.

Theoretical and Policy Framework

Theoretical Framework

Vulnerability is complex and can be measured using various approaches (Ballesteros & Esteves, 2021; Hunter, 2016). It can be measured by either top-down or bottom-up approaches (GIZ, 2014). The top-down approach relies on quantitative data and focuses on predicting biophysical risks and hazards created by climate change and the systems' responses. The bottom-up approach focuses on understanding the impacts of climate change on human systems, usually examining what is referred to as “contextual vulnerability” and its stakeholder-based investigative approaches (Brugère, 2015). The IPCC vulnerability model in 2001 and 2007 took stock of these conceptual developments to define vulnerability. Thus, IPCC combined the key elements of vulnerability from different schools of thought and defined vulnerability as a function of a system’s exposure to change, its sensitivity to it, and its capacity to adapt to it.

As shown in Figure 1, the potential impact is the combination of exposure and sensitivity to climate change. The potential impact on a social system of exposure to a particular climate event or ecosystem change will be determined partly by its sensitivity, particularly when the system depends on natural resources to sustain life. Livelihoods that are highly dependent on such provisioning ecosystem services will be particularly sensitive to the increased exposure to the risk of climate change and variability (Troell et al., 2011).

Adaptive capacity is contextual and differs among communities, countries, societies, and individuals, and it changes over both time and scale (Bhatta et al., 2015; Kom et al., 2022). It can be measured based on the range of accessibility of livelihood capital (i.e. natural, financial, physical, human, and social capital as described in the Sustainable Livelihood Framework (SLF) (Hahn et al., 2009; Islam et al., 2014; Mohamed Shaffril et al., 2015; Sallu et al., 2010). Those lacking the capacity to adapt to climate change will be particularly vulnerable to unpredictable changes, while higher adaptive capacity can help reduce vulnerability (Troell et al., 2011).

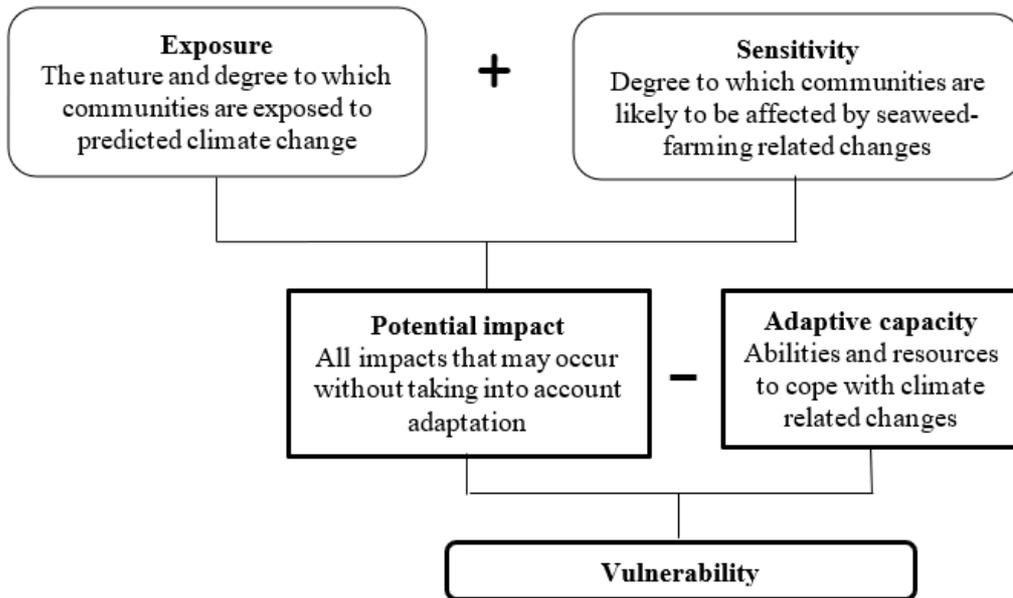


Figure 1: IPCC-Derived Conceptual Model of Vulnerability

Policy Framework for Seaweed Farming

Seaweed farming is one of the livelihood activities that significantly contributes to Zanzibar’s economy. Climate change and seaweed farming are interrelated and have been discussed in some development policies of the Revolutionary Government of Zanzibar (RGoZ). For example, Zanzibar Agriculture Policy 2002 emphasises the need to impart basic aquaculture skills to rural communities and regular studies on the environmental impacts of aquacultural activities. Specifically, the policy encourages research for seaweed culture species, investment in mixed aquatic farming, a transparent and free marketing system for seaweed, and lastly, an introduction of reliable methods for acquiring price information, and the size of markets and their potential for seaweed. Zanzibar Environmental Policy 2013 points out climate change adaptation and mitigation strategies as major national priorities. However, the availability of current climate change data is a challenge for improving upon preparedness and adaptation plans. Despite the limited climate change data, the Environmental Policy 2013 projected the increasingly negative impact of climate change, in which seaweed farming is no exception.

As one of the adaptation strategies, Zanzibar is exploring the development of a thriving blue economy and harnessing the full potential of coastal and sea-based activities. The strategic direction of Zanzibar Development Vision (ZDV) 2050 is to pursue a comprehensive green and blue economy through sustainable management of the environment, natural resources and climate resilience to ensure a sustainable livelihood. The ZDV 2050 emphasises the need for climate resilience to increase agricultural productivity.

Materials and Methods

Study Design and Data Collection

This descriptive cross-sectional study was conducted in Maziwa Ng’ombe and Kiuyu Mbuyuni Shehia in Micheweni District in Pemba, Zanzibar (Figure 2). The reasons for the selection of this study area are fivefold. First, the study area is one of Zanzibar’s leading producers of seaweed. Second, agriculture is the main economic activity in the study area. Third, the study area is exposed

to climate change and variability that prevent rural farmers from achieving sustainable livelihoods. Fourth, the study area is characterised by drought. Fifth, Micheweni is characterised as the poorest district in Zanzibar, with the majority of people living below basic needs and below the food poverty lines. Within the study area, we targeted smallholder farmers who produced seaweed. Those targeted smallholders were mainly the heads of seaweed farming households.

The main data collection instrument was a survey questionnaire. The questionnaire included questions on the socio-economic characteristics of smallholder farmers, the perceived effects of climate change on seaweed farming, the vulnerability of seaweed farmers to climate change, such as exposure, sensitivity and adaptive capacity, and current practices engaged by seaweed farmers to adapt to climate change. Before actual data collection, a pilot survey was conducted. The pilot survey aimed at pretesting the questionnaire to validate the relevance of the questions, given that vulnerability assessment involves a bunch of indicators that are required to be tested and validated to increase the validity and reliability of the instrument. During the pre-test, it was observed that some indicators, e.g., salt water intrusion and the use of water for irrigation, were not relevant to the study area. These indicators were removed from the instrument. Additionally, questions with unexpected response options were adjusted to improve the clarity of the questionnaire before the full survey was deployed. Because of the availability of farmers, the actual survey data were collected from a pragmatic sample size of 183 smallholder seaweed farmers, of which 93 were from Maziwa Ng’ombe Shehia and 90 from Kiuyu Mbuyuni Shehia. Nonetheless, this sample size is adequate for this descriptive study (e.g., Malauri et al., 2021). Additionally, studies show that any reasonable sample size usually suffices for descriptive statistics. The important thing is that the sample size should be appropriate for a given type of analysis (Creswell, 2014; Hair et al., 2006; Snedecor & Cochran, 1989).

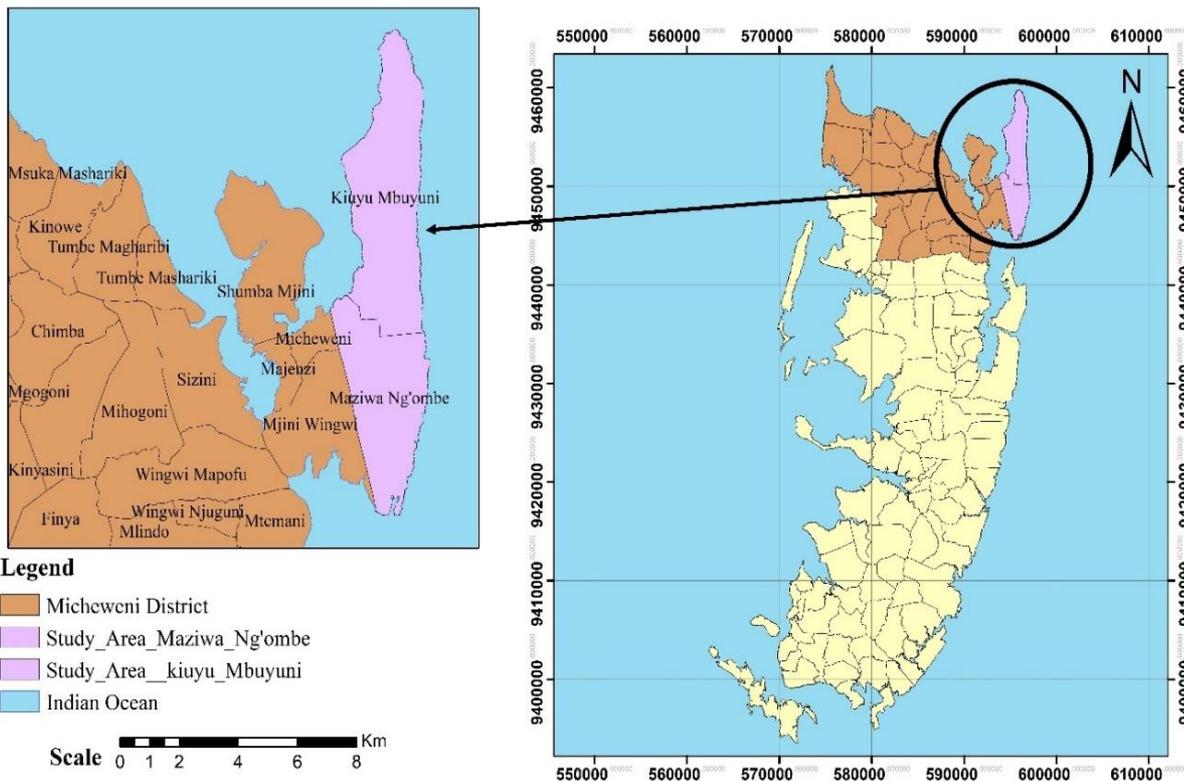


Figure 2: Location of Micheweni District on Pemba Island

Data were collected between February and May 2021. Due to the absence of a formal register of seaweed farmers, researchers walked into seaweed farming households under the escort of *Shehia* (Ward/village) leaders. Those *Shehia* leaders introduced the researchers to the heads of seaweed farming households. After the introduction, the researchers explained the purpose of the study to the heads of the seaweed farming households and asked for verbal consent to participate in the survey. Participants were further informed that participation in this survey was voluntary; that answers are anonymous; that they may skip some of the questions or quit participation at any stage; and that by completing the survey, they have agreed that the collected information can be used for academic purposes. Although participation in this study was voluntary and participants were free to quit at any stage or to skip some of the questions, all participants completed the survey.

While the absence of a formal register necessitated a convenient sampling approach escorted by *Shehia* leaders, this method, though practical in resource-constrained rural settings, introduces potential biases that warrant consideration. Selection bias may arise as leaders could preferentially introduce researchers to more accessible, cooperative, or prominent households within their networks, potentially overrepresenting certain demographic groups (e.g., those with stronger community ties or higher visibility) and underrepresenting remote, marginalized, or less engaged farmers. Despite these limitations, we continued sampling until the target size was met across two *Shehia*. This was aimed at enhancing diversity, and the sample's demographic alignment with district profiles (e.g., high female representation consistent with seaweed farming's gendered nature) suggests reasonable representativeness for descriptive purposes

Data Analysis

Data were analysed using simple descriptive statistics, aimed at portraying a picture of the vulnerability of seaweed farmers and their adaptation to the effects of climate change in the study areas. Although this study did not aim to meet any level of statistical significance, the Chi-square test was used to determine the association between various climate change adaptation strategies and the sex of heads of seaweed farming households. While other analyses were done on IBM SPSS, MS Excel was used for the computation of the Livelihood Vulnerability Index (LVI). LVI was computed using the IPCC methodology with a balanced weighted average approach. This approach ensures that each sub-component contributes equally to the overall index, even though each major component of different livelihood assets includes a different number of sub-components. The calculation of LVI follows the method Simane et al. (2016) used in agroecosystem-specific climate vulnerability analysis.

According to the IPCC, LVI is a function of potential impact (i.e., exposure and sensitivity) and adaptive capacity, as shown in equation 1.

$$LVI = (Exposure - Adaptive\ capacity) \times Sensitivity \quad (1)$$

Appendix 1 presents contributing factors to livelihood vulnerability in the study area, including exposure, sensitivity and adaptive capacity as assessed using five livelihood capitals and sub-components with each capital (i.e. human capital, social capital, natural capital, physical capital, and financial capital). Each sub-component was computed with different scales and indicators from which the normalisation of sub-components was calculated. The formula for normalisation was adopted from the Human Development Index, as shown in equation 2.

$$Index\ S_d = \frac{S_d - S_{min}}{S_{max} - S_{min}} \quad (2)$$

S_d is the actual value of the sub-components of the area d (Maziwa Ng'ombe and Kiuyu Mbuyuni *Shehia*), while S_{max} and S_{min} indicate the maximum and minimum values of each sub-component, respectively, determined by the data from the study area. For variables that measure frequencies, such as the "per cent of households using the ocean for farming activities, the minimum value was set at zero and the maximum value at 100. Once standardised, the

sub-components were averaged using the formula in equation 3, and then the value of their main components was calculated.

$$M_d = \frac{\sum_{i=1}^n Index\ S_{di}}{n} \quad (3)$$

The value of M_d is equal to one of the main components in area d (exposure to climate variability and natural disaster, sensitivity to natural capital and human, natural, physical, financial and social capital). The d_i index reflects the value of the sub-components that are indexed by i from the adaptive capacity (i.e. health, food, knowledge and skills, ocean, land, water, demographic, network and relationship, asset, finance, road and communication). Based on equation 3, the LVI grades can be obtained by using equation 4.

$$CF_d = \frac{\sum_{i=1}^n W_{mi} M_{di}}{\sum_{i=1}^n W_{mi}} \quad (4)$$

CF_d represents the contributing factors according to IPCC (exposure, sensitivity or adaptive capacity) for area d . M_{di} represents the main component for area d , which is indexed by i . W_{mi} represents the quality of the main component and n represents the number of the main components of each contributing factor. From equation 1 and subsequent derivations, the combination of these three contributing factors is calculated using equation 5.

$$LVI_d = (e_d - a_d) \times S_d \quad (5)$$

Where LVI_d represents the LVI index in area d expressed by using the framework of the vulnerability of the IPCC; e represents exposure score of area d (equal as the main component of natural disaster and climate variability); a represents the adaptive capacity score of area d (weighted by

the average of the main components) and S_d represents a sensitivity score of area d (weighted by the average of the major component). According to IPCC, the scales of LVI are interpreted as follows: the range between -1 and -0.4 is 'not vulnerable'; the range between -0.41 and 0.3 is 'vulnerable' or 'moderate'; and the range between 0.31 and 1 is 'very vulnerable'.

Results

Demographic Characteristics of Respondents

Results showed that about three-quarters of seaweed farmers in Micheweni District were female (Table 1). Consistent with previous studies, most of these seaweed farmers were married (e.g., Ali, 2018; OCGS, 2020; Rijja & Buriyo, 2020). Although we aimed to interview heads of farming households, most of whom were men (OCGS, 2020), women were more positioned to provide accurate answers to the survey than men. This is because in the study areas, seaweed farming was considered a female rather than a male activity. Men were principally engaged in petty coastal fishing or other economic activities, and some of them were sporadically helping women in seaweed production. Additionally, seaweed farming allows women to work close to their homes while managing other household chores.

Like Rijja and Buriyo (2020), the predominant age group in seaweed production was within 30 to 44-year-old, most of whom had lived in Micheweni for over 20 years. This implies that most seaweed farmers have farming experience and knowledge of the Micheweni area. While it was expected that long-term residency would influence perceptions and adaptation to climate change, this study did not find a significant correlation. The absence of a significant correlation between long-term residency and seaweed farmers' perceptions or adaptation to climate change, despite initial expectations, can be attributed to the homogenizing effects of pervasive environmental stressors and entrenched place attachment. With over 80% of participants having resided in the area for more than 20 years, the sample exhibits limited variability in residency duration, potentially masking nuanced differences in experiential knowledge and leading to a uniformly heightened awareness of climate impacts such as rising ocean temperatures and irregular winds, which affect all farmers irrespective of slight variations in tenure (e.g., Parreira & Mouro, 2023).

Table 1: Demographic Characteristics of Seaweed Farmers (%)

Variable	Maziwa Ng'ombe (n = 93)	Kiuyu Mbuyuni (n = 90)	All (n = 183)
Sex			
Male	23.7	31.1	27.3
Female	76.3	68.9	72.7
Total	100.0	100.0	100.0
Age			
18-29	8.6	4.4	6.6
30-44	47.3	53.3	50.3
45-64	33.3	34.4	33.9
65+	10.8	7.8	9.3
Total	100.0	100.0	100.0
Education level			
Nonformal education	67.7	60.0	63.9
Primary education	19.4	27.8	23.5
Secondary education	7.5	8.9	8.2
Post-secondary education	5.4	3.3	4.4
Total	100.0	100.0	100.0
Marital status			
Single	8.6	15.6	12.0
Married	76.3	68.9	72.7
Divorced	4.3	5.6	4.9
Separated	4.3	2.2	3.3
Widow/widower	6.5	7.8	7.1
Total	100.0	100.0	100.0
Time in years lived in Micheweni			
Between 1- 20 years	12.9	25.6	19.1
Between 21- 40 years	50.5	45.6	48.1
Between 41- 60 years	28.0	20.0	24.0
More than 60 years	8.6	8.9	8.7
Total	100.0	100.0	100.0

Surprisingly, about two-thirds of the respondents had no formal education whatsoever. Only about 24% had attained primary education, while secondary or post-secondary education attainment was negligible. This phenomenon is not uncommon in Micheweni District, where, according to OCGS (2020), the net primary enrolment is lowest at 67.9% compared to the Zanzibar average net enrolment of 85.7%. Additionally, about 34% of the over-15-year-old population in Micheweni is illiterate (OCGS, 2020). In either case, the high proportion of seaweed farmers with no formal education may imply that seaweed production is dominated by people who did not go to school. These subsistent farmers may be producing seaweed by default as a necessity rather than by choice.

Livelihood Vulnerability of Seaweed Farmers

As shown in Table 2, exposure, sensitivity, and adaptive capacity indexes were established. Exposure is related to the climate stress level or the degree to which people and the things they value can be exposed to climate change. The exposure index in this study was measured between 2010 and 2019 using four main indicators: mean maximum temperature, mean minimum temperature, mean precipitation, and flood, as shown in Table 2. In both sites, i.e. Maziwa Ng'ombe and Kiuyu Mbuyuni, the exposure to climate change was measured using the same statistical meteorological data, given a similarity of climate statistics. The overall exposure index of 0.64, indicating moderate to high exposure, was primarily driven by ocean temperatures and changes in precipitation patterns, alongside the documented frequency of flood events between 2010 and 2019.

Sensitivity, the degree to which exposure to climate change could harm the community, was also established using three main indicators, as shown in Table 2. The overall sensitivity index for both sites was estimated at 0.74, which indicates that the farming system was highly sensitive. This observation was interpreted to mean that small climate changes can significantly impact productivity. High dependence on natural resources increases sensitivity to exposure due to the susceptibility of natural resources to climate change.

Among the remarkable disasters reported in Micheweni District between 2010 and 2019 were floods and landslides, particularly in 2017. These disasters caused the deaths of people and livestock and destroyed houses, schools, and road infrastructure. It is estimated that 56% of farming households were affected (Integrated Food Security Phase Classification (IPC), 2017). Production of crops also declined. This resulted in food shock, particularly for households that rely on self-produced food for household consumption.

The severity of sensitivity to exposure depends on the adaptive capacity of the population in question. Adaptive capacity, the degree to which the respective population could mitigate the potential for harm by taking action to reduce exposure to sensitivity, is an important element of long-term adaptation to climate change (Siders, 2019). In this study, adaptive capacity was measured by the range of accessibility of livelihood resources as described in the theory of SLF. As shown in Appendix 1, adaptive capacity included five livelihood capitals as principal components and 12 subcomponents with 37 indicators. The overall adaptive capacity index was 0.49, implying a low to moderate ability to adapt, lower than exposure and sensitivity, highlighting a gap in coping mechanisms, as shown in Table 2. The accessibility of social and human capital was slightly higher compared to financial, physical, and natural capital. Thus, the ability of seaweed farmers in Micheweni District to minimise risks related to climate change is characterised as weak. Based on the established exposure, sensitivity, and adaptive capacity indexes, the overall Livelihood Vulnerability Index (LVI) was calculated using the IPCC framework, as shown in Equation 1. Results showed that LVI was 0.27, indicating moderate vulnerability, which suggests manageable, but notable risks.

Table 2: Livelihood Vulnerability of Seaweed Farmers

Variable	Maziwa Ngo'ombe	Kiuyu Mbuyuni	Overall Index
1. ADAPTIVE CAPACITY			
Human Capital			
Heath	0.22	0.21	0.22
Food	0.58	0.63	0.61
Knowledge and Skills	0.49	0.51	0.5
Overall Human Capital Index	0.39	0.41	0.4
Natural Capital			
Ocean	0.41	0.33	0.37
Land	0.45	0.39	0.42
Water	0.62	0.67	0.65
Overall Natural Capital Index	0.51	0.49	0.5
Social Capital			
Demographic	0.59	0.60	0.6.
Network and Relationship	0.74	0.76	0.75
Overall Social Capital Index	0.68	0.70	0.69
Financial Capital			
Physical assets	0.00	0.00	0.00
Finance	0.36	0.44	0.40
Overall Financial Capital Index	0.27	0.33	0.31
Physical Capital			
Road	0.35	0.38	0.37
Communication	0.59	0.64	0.62
Overall Physical Capital Index	0.51	0.55	0.53
OVERALL ADAPTIVE CAPACITY INDEX	0.49	0.49	0.49
2. SENSITIVITY			
Percentage of households reported a loss of physical assets (house/machinery) due to flooding within the last 10 years	0.28	0.15	
Percentage of households reported decreasing agriculture productivity	1.00	1.00	
Percentage of households reported use of natural resources for survival	1.00	1.00	
OVERALL SENSITIVITY INDEX	0.76	0.72	0.74
3. EXPOSURE			
Mean standard deviation of daily mean average maximum temperature by month (from 2010-2019)			0.87
Mean standard deviation of daily mean average minimum temperature by month (from 2010-2019)			0.63
Mean standard deviation of daily precipitation by month (from 2010-2019)			0.71
The average number of floods (from 2010-2019)			0.33
OVERALL EXPOSURE INDEX			0.64

Perceived Effects of Climate Change on Seaweed Farming

Given the livelihood vulnerability, the study examined the perceived effects of climate change on seaweed farming, specifically on seaweed growth, production, and block stability as shown in Table 3. Also, we explored seaweed farmers' perceptions of the degree of effects, seasons of high and lean production, and seasons characterised by block instability. All interviewed farmers felt the effects of climate change on seaweed production. Those farmers perceived that the effects of climate change on seaweed farming were higher in seaweed growth and production than in block instability, mainly due to the increase in water temperature.

As stated earlier, we asked seaweed farmers to mention the seasons of high and lean production and those characterised by seaweed block instability. This question aimed to understand the characteristics of the climatic conditions of each season and how they can affect seaweed farming. Results showed that the rain and cold seasons were favourable times for seaweed production; attributable to the decline in water temperature, which is conducive to seaweed farming. The hot season was perceived as a period of low production due to the high ocean water temperature. This is evident from the findings of Msuya & Hurtado (2017) that also show that *spinosum* and *cottonii* cultivated in Zanzibar are growing optimally between 21 and 31°C and that the West India Ocean (WIO) region has seen an increase in surface seawater temperatures of 37 to 38 °C.

Seaweed farmers perceived that the wind season, particularly the North-eastern and South-eastern winds, highly affected seaweed block instability. The North-eastern and South-eastern winds characterise the weather conditions of Zanzibar. The north-eastern wind, commonly known as *kaskazi*, blows between November/December and March and is accompanied by warm conditions (summer). The south-eastern wind, commonly known as *kusi* blows between June and September, a very strong wind accompanied by colder weather (winter). Those winds from strong ocean waves affect seaweed blocks by breaking seaweed branches (Besta, 2013; Makame, 2013). Subsequently, farmers have to re-fix their pegs and replant the seaweed. Although strong, the south-easterly wind is favourable for seaweed growth because it is experienced in the cooler season, compared to north-easterly winds in the hot season.

To further understand the effects of climate change on seaweed farming, respondents were asked to recall the average seaweed production per year in the last five years between 2016 and 2020. As shown in Figure 3, the average household seaweed production per year decreased drastically within the last five years from more than four tons in 2016 to less than three tons in 2020. Similarly, Msuya & Porter (2014) report a decrease in seaweed production in Songosongo Island from above 400 tons in 2003 to less than 50 tons in 2012. Nonetheless, this is not surprising since the general trend of seaweed production in Zanzibar has decreased over time (e.g., Makame et al., 2021).

Table 3: Perceived effects of climate change on seaweed farming

Variables	Responses	Seaweed growth (n = 183)	Seaweed production (n = 183)	Block stability (n = 183)
Effect on stated variable	Yes	100.0	100.0	96.2
	No	-	-	3.8
Degree of Effect	Total	100.0	100.0	100.0
	High effect	73.2	88.0	63.6
	Moderate effect	24.0	10.4	21.6
	Low effect	2.7	1.6	14.8
	Not at all	-	-	-
High production season	Rainy season	70.5	88.5	77.6
	Cold season	62.3	73.8	NA
	Short rain season	11.5	5.4	NA
Lean or low production season	Hot season	100.0	100.0	NA
Season of block instability	South-easterly wind	NA	NA	50.8
	North-easterly wind	NA	NA	86.2

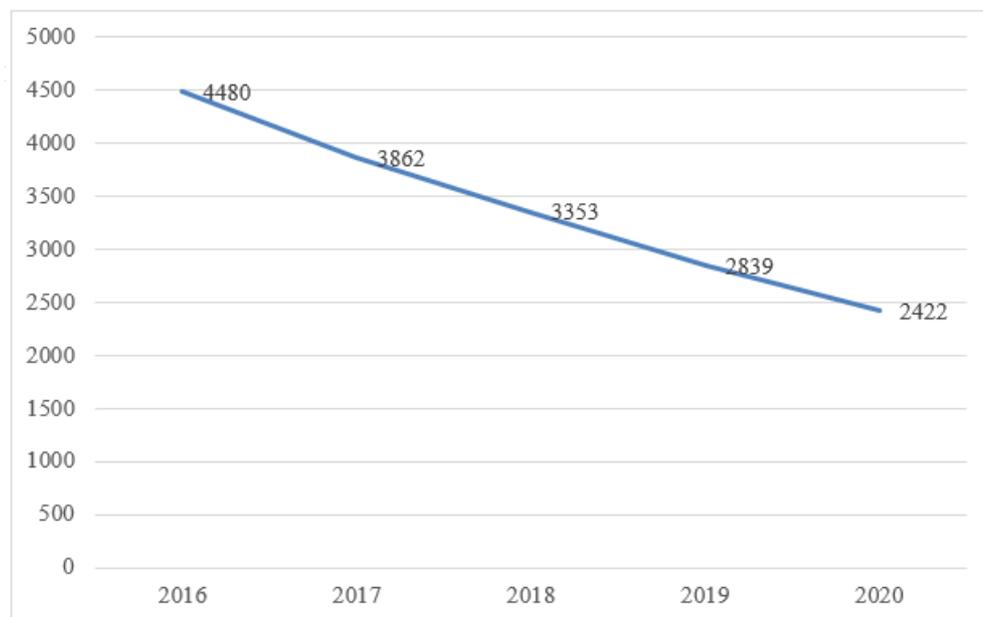


Figure 3: Average annual household seaweed production (kg) in Micheweni

Current Practices of Seaweed Farmers in Adapting to the Effects of Climate Change

Due to exposure and sensitivity to climate change, we examined other practices that seaweed farmers engaged in to reflect adaptive capacity based on accessibility to livelihood assets. As shown in Table 4, nearly 70% of respondents changed their farming practices in response to the effects of climate change. A similar report has been presented by earlier scholars (e.g., Lumenyela et al., 2023). The Chi-square test indicates a statistically significant association between the decision to change farming practices and respondents' sex ($p < 0.000$). Some of the farming practices in adapting to the effects of climate change included: cultivation of seaweed in deep water; planting seaweed during wet/cooler seasons; increasing the number of and placing cages closer to one another during strong wind/ocean waves; and fixing very hard and long wooden cages deep into the ground. Cultivation of seaweed in deep water is highly recommended by previous studies (e.g., Largo

et al., 2020; Msuya & Porter, 2014; Rijja & Buriyo, 2020). This is because of the consistency and stability of water temperature and salinity, which is favourable for seaweed growth and a lower prevalence of diseases.

Apart from the aforementioned changes in farming practices, seaweed farmers practised crop diversification and undertook alternative economic activities. Regarding crop diversification, only about a third of respondents practised it to reduce over-dependency on seaweed as the main cash crop for income generation among farmers. Crops produced as part of the diversification strategy were either food crops, cash crops, or both food and cash crops. However, the Chi-square test did not indicate any significant statistical association between the decision to diversify crop production and the respondents' sex ($p > 0.100$). This could be because in Zanzibar, it is not uncommon to observe women cultivate crops from land owned by their husband, family, friend, neighbour or relative. The cultural practice of Zanzibar encourages people within the community to help each other.

Table 4: Current Practices of Seaweed Farmers in Adapting to the Effects of Climate Change

Variable	Response	Maziwa Ng'ombe (n = 193)		Kiuyu Mbuyuni (n = 90)		All (n = 183)		Total	Test statistic	
		Male	Female	Male	Female	Male	Female		Chi-square	P-Value
Change of seaweed farming practices	Yes	23.7	55.9	30.0	54.4	24.6	44.3	68.9	14.347	0.000
	No	0.0	20.4	1.1	14.4	2.7	28.4	31.1		
Crop diversification	Yes	5.4	25.8	8.9	30.0	7.1	27.9	35.0	2.436	0.119
	No	18.3	50.5	22.2	38.9	20.2	44.8	65.0		
Alternative economic activities	Yes	20.4	18.3	18.9	16.7	19.1	20.2	39.3	27.092	0.000
	No	3.2	58.1	12.2	52.2	8.2	52.5	60.7		
If Yes, what is the main alternative economic activity?	Fisheries	17.5	7.5	21.9	0.0	19.4	4.2	23.6	28.073	0.000
	Block mining	12.5	2.5	18.8	0.0	15.3	1.4	16.7		
	Small business	5.0	17.5	3.1	21.9	4.2	19.4	23.6		
	Livestock keeping	10.0	27.5	9.4	25.0	9.7	26.4	36.1		

Nearly 40% of respondents practised alternative economic activities, as shown in Table 4. The Chi-square test shows a significant statistical association between the decision to undertake alternative economic activities and respondents' sex ($p < 0.000$). The main alternative economic activities included livestock keeping, fisheries, petty businesses, and block mining. Our results are consistent with Songwe et al. (2016), who show that most seaweed farmers are engaged in additional economic activities such as agriculture, retail business, fishing, and stone quarries.

Discussion

Although we attempted to find respondents from various age groups, marital statuses, education, and genders equally, our final sample was biased towards females, the age cohort of 30 to 44 years, non-formal education, and married seaweed farmers. These could be considered the main characteristics of seaweed farmers, mostly married women of middle age with no formal education. Given these characteristics, it can be argued that seaweed farming is dominated by women who have limited economic opportunities given their level of education and so are at the bottom of the pyramid. This low literacy may limit access to extension services or innovative adaptations, reinforcing subsistence farming by necessity rather than choice. Compared to Zanzibar's average (85.7% net primary enrollment), Micheweni's 67.9% highlights

systemic barriers. These demographics underscore gender and education as key vulnerability factors, as women and low-educated groups often bear disproportionate climate burdens in coastal communities.

Thus, consistent with previous studies (Makame, 2013; Makame et al., 2018; Matoju et al., 2022), this paper has established that seaweed farmers were highly exposed to climate change, and the sensitivity or the degree to which the exposure to climate change could be harmful was also high. Since the Pemba Island is located in the Indian Ocean, warming waters and changing precipitation patterns likely expose farmers to risks such as temperature stress on seaweed, which thrives within specific thermal ranges. Exposure to such stressors, including changing temperatures, unpredictable rainfall, and wind speed and direction, threatens seaweed farming, a significant economic activity of women in the study areas. Increasing temperature is associated with increased incidence of diseases, including ice-ice disease and epiphyte intensification, which undermine seaweed growth (Bernard et al., 2024). In addition, wind speed and changes in wind direction with high ocean waves affect seaweed block stability, thereby making seaweed production a seasonal activity.

Sensitivity was high (0.74), suggesting that the effects of climate change were high. Seaweed species, such as those commonly farmed in Zanzibar, have narrow optimal conditions for growth, particularly regarding changes in temperature, wind speed and direction. Minor deviations, such as those caused by climate variability, can lead to reduced productivity or quality degradation. The high sensitivity echoes the paper's context of poverty (48.1% basic needs poverty in Micheweni) and ecosystem dependence, where small changes amplify impacts. Compared to similar studies (e.g., in sub-Saharan fisheries), this highlights how low adaptive capacity exacerbates vulnerability in island settings. Low adaptive capacity relative to exposure and sensitivity contributes to high vulnerability.

The results indicate a complex vulnerability profile for seaweed farmers on Pemba Island. The high exposure (0.64) and sensitivity (0.74) underscore the direct threats from climate change, such as warming oceans. Warming oceans reduce seaweed yields and quality, a finding that aligns with previous research indicating that climate variability is straining East African coastal communities (Sultana et al., 2023). The moderate adaptive capacity (0.49) suggests that while farmers have some coping mechanisms, such as shifting farming locations or adopting new techniques, these are insufficient to mitigate the impacts fully, particularly given the economic constraints on seaweed farmers, who are predominantly resource-constrained women. The low-to-moderate adaptive capacity is particularly constrained by limited financial and physical assets, as detailed in Appendix 1, which restricts farmers' ability to invest in more resilient farming methods or diversify livelihoods. This aligns with findings from de Jong Cleynert et al. (2021), where similar asset poverty limits adaptive responses.

The LVI of 0.27, indicating moderate vulnerability, suggests that while the situation is concerning, there is room for intervention. This is particularly important given the seaweed farming's role in empowering women and supporting the local economy (Vox, 2023). The moderate vulnerability also highlights an unexpected opportunity: seaweed farming itself can contribute to climate adaptation, acting as a carbon sink and reducing ocean acidification locally, which could be leveraged for sustainability (Sultana et al., 2023).

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This study revealed that farmers are facing the effects of climate change on seaweed production. Due to rising water temperatures, the negative impact on seaweed growth and production outweighed concerns about block instability. Furthermore, many farmers changed their farming practices in reaction to climate change. These adaptive strategies included growing seaweed in deeper waters, planting during the wetter or cooler seasons, and securely anchoring long, sturdy stakes deep in the ground. Alongside these modifications, seaweed farmers pursued crop diversification and sought alternative economic opportunities.

Conclusion and Recommendations

The study portrays seaweed farmers on Pemba Island as moderately vulnerable to climate change, characterised by high exposure and sensitivity, but mitigated by some adaptive capacity. It concludes that while seaweed farmers can cope with current climate risks to some extent, their livelihoods remain precarious. Without targeted and context-specific interventions to strengthen adaptive capacity, continued climate change is likely to exacerbate livelihood insecurity, deepen poverty, and undermine the sustainability of seaweed farming as a key component of Zanzibar's blue economy. Training on climate-resilient farming, introducing tolerant seaweed varieties, and supporting livelihood diversification are vital for strengthening adaptive capacity. Moreover, further research could evaluate the effectiveness of specific adaptation strategies for seaweed farmers in the face of climate change. Such research would offer practical insights into resilience and sustainability of seaweed farming.

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Appendix 1: Indicators and indices for adaptive capacity

Indicators	Maziwa Ngo'ombe		Kiuyu Mbuyuni		Overall Index
	Actual value %	Index	Actual value %	Index	
Human Capital					
<i>Health</i>					
Percent of HHs reported at least one chronically ill member (HIV, Malaria, TB, Cholera)	21.1	0.21	10.5	0.11	
Percent of HHs where a family member had to miss farm work due to illness in past one 1 month	25.1	0.25	20.5	0.21	
Average time to nearest health center (minutes)	7.45	0.46	9.01	0.57	
Percent of HHs where a family member is infected by a communicable disease	29	0.20	14.4	0.14	
% Households with members needing dependent care	11.8	0.12	18.9	0.19	
Percent of HHs who do not have toilet	7.8	0.08	4.1	0.04	
Average health index		0.22		0.21	0.22
<i>Food</i>					
Percent of households primarily dependent on self-farmed food	31.2	0.31	26.7	0.27	
Percent of HH that does not have enough food for family consumption	53.8	0.54	68.5	0.69	
Percentage of households without crops savings	89.2	0.89	93.3	0.93	
Average food index		0.58		0.63	0.61
<i>Knowledge and Skills</i>					
Percent of HHs has not access education services	15.2	0.15	23.4	0.23	
Percent of HHs not having TV at home	75.3	0.75	81.1	0.81	
Percent of HHs not having radio set at home	16.1	0.16	21.1	0.21	
Percent of HHs has not access extension services	36.6	0.37	27.8	0.28	
Percentage of HH access to environmental education	100	1.00	100	1.00	
Average knowledge and skills index		0.49		0.51	0.5
Natural Capital					
<i>Ocean</i>					
Percent of HH using ocean for fishing activities	40.9	0.41	33.3	0.33	
Average ocean index		0.41		0.33	0.37
<i>Land</i>					
Percentage of HH without ownership of land	75.3	0.75	67.8	0.68	
Percentage of HH report Land suitability for agriculture	14	0.14	11.1	0.11	
Average land index		0.45		0.39	0.42
<i>Water</i>					
Percent of households that utilize a natural water source	100	1.00	100	1.00	
Average time to source of water	2.62	0.23	3.4	0.34	
Average water index		0.62		0.67	0.65
Social Capital					
<i>Demographic</i>					
Dependency Ratio	55.49	0.55	60.05	0.60	
Percent of female-headed HHs	76.3	0.76	68.9	0.69	
Average family member in a HHs	6.1	0.46	6.61	0.51	
Average demographic index		0.59		0.60	0.6
<i>Network and Relationship</i>					
Percent of HHs who have not received any kind of support and help from neighbor in past one month	81.7	0.82	72.2	0.72	
Percent of HHs who have not given any support and help to neighbor in past one month	86	0.86	92.2	0.92	
Percent of HHs that have not gone to local government for any kind of assistance in past 12 month	81.7	0.82	86.7	0.87	
Percent of HHs without member(s) working outside community	81.7	0.82	74.8	0.75	
Percent of HHs where a family member is not associated with any CBO	40.9	0.41	55.1	0.55	
Average network and relationship		0.74		0.76	0.75
Financial Capital					
<i>Physical assets</i>					
Percent of HH owning physical assets such as radio, TV, smartphone, house, livestock, furniture, boat,	0	0.00	0	0.00	
Average physical asset		0.00		0.00	0.0
<i>Finance</i>					
Percent of HH save money for future uses	18.3	0.18	24.4	0.24	
Percent of HHs who have debt to pay back to individual lender	22.6	0.23	37.8	0.38	
Percent of HHs who do not have access to financial services to any financial institution	66.7	0.67	70	0.70	
Average finance asset		0.36		0.44	0.4
Physical Capital					
<i>Road</i>					
Average time to reach nearest vehicle station/ road for transportation/ bus station	6.05	0.27	4.82	0.20	
Average time to reach marketplace	7.11	0.44	8.72	0.55	
Average road index		0.35		0.38	0.37
<i>Communication</i>					
Percentage of HHs connected to water supply	100	1.00	100	1.00	
Percentage of HH connected to electricity supply	63.4	0.63	72.2	0.72	
Percentage of HHs using telephone	11.8	0.12	17.8	0.18	
Percentage of HH Access to weather information	60.2	0.60	64.4	0.64	
Average communication index		0.59		0.64	0.62