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Integrating Local and Modern Knowledge for Climate Change Adaptation in Sustainable Seaweed Farming in Zanzibar

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Abstract

In Zanzibar, seaweed cultivation serves as a vital economic activity for coastal populations, offering income opportunities and enhancing food security. Nevertheless, the industry is confronting unprecedented challenges due to climate change effects, such as elevated ocean temperatures, increased acidity, and severe weather events. This research provided a comprehensive examination of how local knowledge and contemporary scientific understanding are being integrated to adapt seaweed farming practices to climate change in Zanzibar. Traditionally, indigenous knowledge has been fundamental to seaweed farming in Zanzibar. Local cultivators have established long-standing methods based on their observations of marine ecosystems and natural cycles. These traditional practices are deeply embedded in the community's cultural heritage, emphasizing sustainable resource utilization. However, recent climate changes have disrupted these conventional techniques. Elevated sea temperatures have resulted in decreased seaweed production, while erratic weather patterns and more frequent storms have caused damage to seaweed farms. To address these issues, researchers have increasingly focused on incorporating modern scientific insights and technological advancements into traditional seaweed cultivation methods. The investigation was conducted in Zanzibar, specifically in Chwaka Bay, encompassing the coastal communities of Chwaka, Uroa, and Marumbi with 346 respondents. The area was selected due to its high concentration of seaweed farmers who depend on seaweed cultivation for their livelihood. For the purpose of this study, cross-sectional design was used. The design was suitable in this study because the data was collected in single point at a time by using different data collection methods. The study involved both primary and secondary data. Primary data was obtained from the field using questionnaire and key informant interview. Secondary data was obtained from reviewing readings from various literatures related to the study. The study's findings indicated that conventional farming practices were augmented with innovative approaches, including integrated aquaculture, advanced seedling production, and more efficient harvesting techniques. Moreover, local communities were actively involved in climate change adaptation initiatives, fostering a sense of ownership and responsibility for the long-term viability of seaweed farming. The integration of indigenous and modern knowledge systems proved crucial for adapting Zanzibar's seaweed industry to climate change. This integrated approach not only enhances the resilience of coastal communities but also promotes sustainable resource management and contributes to global efforts in mitigating climate change impacts on vulnerable ecosystems and livelihoods.

Subject Areas

Environmental Sciences

Keywords

Climate Change, Seaweed Farming, Adaptation, Modern and Traditional Methods

1. Introduction

Seaweed cultivation is conducted on a limited scale globally for various applications in food, medicine, and cosmetics across diverse climatic conditions [1]. Researchers in Asian nations such as China, Korea, and Japan advocate for the development of large-scale seaweed farms. Their proposal involves cultivating seaweed to maturity, harvesting it, and subsequently depositing it in deep ocean waters. This process would sequester captured carbon dioxide for centuries or millennia, potentially mitigating climate change effects [2]. The promotion of seaweed farming as a livelihood source is well-supported. A Philippine news outlet reported that approximately 1,000,000 families rely on seaweed cultivation for their income. The report cited an industry study indicating that a 1000 square meter seaweed farm could serve as the primary income source for an average family [3]. In Capsalay Island, Palawan, Philippines, a USAID-funded initiative (CRMP) facilitated the establishment of seaweed farming as an additional income stream for a fishing-dependent community [4]. The project provided technical support and initial materials to 24 families and groups who adopted seaweed farming [3]. Research suggests that cultivating microalgae in just 0.001 percent of global seaweed-suitable waters and subsequently burying it at sea could offset the entire carbon emissions of the rapidly expanding global aquaculture industry, which provides half of the world's seafood [5]. The study concluded that 18.5 million square miles of ocean are suitable for seaweed cultivation [6].

Seaweed offers multiple environmental benefits beyond its potential to counteract acidification and deoxygenation, absorb excess nutrients, and provide marine habitats in at least 77 countries. It can also be processed into biofuel [7]. Studies have demonstrated that incorporating seaweed into livestock feed can reduce methane emissions from ruminant animals, a significant source of greenhouse gases, by up to 70 percent. Additionally, seaweed can be utilized as an agricultural soil supplement, replacing petroleum-based fertilizers [8]. Scotty Schmidt, CEO of Primary Ocean, a Los Angeles-based company involved in a U.S. government-funded project to develop large-scale seaweed farming technologies, states, "Seaweed can be a very effective tool to fight climate change, but it has to be validated by the market" [9]. Despite this potential, some highly suitable locations have yet to attract commercial development and investment from the seaweed farming industry. In Tanzania, seaweed harvesting commenced in the early 1950s, with native species collected from the intertidal zones of coral reefs. The primary species were Eucheuma denticulate, commonly known as spinosum, and Kappaphycus striatum and K. Alvarazii, which naturally occur along Tanzania's coastline [10] [11].

Commercial seaweed farming on Tanzania's mainland began in 1994, utilizing two exotic strains of cottonii and spinosum. The cultivation techniques were initially introduced from the Philippines and subsequently modified to better suit the local environment. In Tanzania, private sector entities provided technical assistance and financial support through equipment and supplies, emphasizing coastal community involvement. Seaweed has become a valuable addition to Zanzibar's traditional exports, including coconuts, cloves, and other spices. The success of commercial seaweed production led to the establishment of other ventures such as ZASCOL and C-Weed corporation. A subsequent trial yielded growth rates of 6% to 7% daily [7], indicating the suitability of exotic strains for commercial cultivation. Seaweed farming was introduced on Unguja's east coast, becoming a significant source of income for coastal inhabitants. The concept of traditional local knowledge is well-established in the human sciences. Anthropologists and sociologists have developed theories since the 1930s and 1940s, such as Redfield's "folk-urban continuum" concept [2].

More recently, knowledge has been considered in preventing and mitigating climate variability-related phenomena such as flooding, droughts, and hurricanes. In the past decade, studies have aimed to incorporate local knowledge in disaster risk reduction [12] [13]. Research has also focused on local perceptions of hurricane risks [14]. Additionally, adaptation strategies based on traditional knowledge have been identified for flood [15] and drought [16] prevention. The integration of local knowledge into disaster risk reduction (DRR) was proposed by [13] following the 1999 Vanuatu tsunami. The study examined people's responses to the tsunami, focusing on local knowledge rather than the early-warning system. The low number of casualties was attributed to individuals' ability to recognize tsunami warning signs, a skill linked to tradition-based indigenous knowledge (Kastom stories) and myths. [12] also suggested incorporating traditional knowledge in DRR for Indonesia's coastal populations. The study revealed that coastal communities on small Indonesian islands possess robust local knowledge for predicting hydro-meteorological threats through observations of the sky, sea, clouds, animals, plants, and insects. [14] investigated local perceptions of hurricane risk among communities in El Zapotito, Veracruz, demonstrating how these perceptions can be integrated into risk management. The model used in this study is based on the local community's perception. Research in a Zoque community in Chiapas [17] demonstrated that local perception of climate change has enabled people to modify their agricultural calendar for planting and harvesting. The Zoque community had observed changes in annual rainfall patterns, rising temperatures, and varying durations of "northers".

Research conducted by [15] in Muzarabani, Zimbabwe, revealed that local communities have implemented strategies to prevent and mitigate flooding for various reasons, including safeguarding possessions, residences, and crops, as well as conserving water and food supplies. In a separate Zimbabwean community, [16] noted the utilization of diverse traditional indicators to forecast droughts in the Msingwane Catchment area. These indicators included observations of trees, plants, insects, birds, animals, wind patterns, and the appearance of the moon and sun at different times throughout the year. The majority of these indicators are observed shortly after winter and as the rainy season commences [18]. These experiences generally support the argument presented by [19] that community knowledge has enabled the development of practices, methods, and habits that have, over time, contributed to effective risk and disaster prevention strategies. In the Yucatán, researchers also identified adaptive practices for addressing hydro-meteorological events. However, these practices have undergone gradual modifications, and many authors cited do not consider the social and cultural changes that have been altering these customs [5]. In this context, practices and observations rooted in local knowledge have necessarily evolved and sometimes disappeared. Nevertheless, the authors propose a working hypothesis that some elements of this traditional knowledge persist [6].

Consequently, this study investigated the integration of local and modern knowledge in the context of climate change for three villages engaged in seaweed farming: Chwaka, Marumbi, and Uroa, located in Chwaka Bay within the South Region of Unguja Island. Specifically, the study aimed to identify climate change adaptation strategies among seaweed farmers, examine the impact of utilizing modern and local seaweed farming methods, and assess farmers' awareness of climate change for sustainable seaweed farming and its effects on livelihoods.

2. Methodology

2.1. Study Area

The investigation was conducted in Zanzibar, specifically in Chwaka Bay, encompassing the coastal communities of Chwaka, Uroa, and Marumbi (**Figure 1**). This area was selected due to its high concentration of seaweed farmers who depend on seaweed cultivation for their livelihood. The location provided the researcher with valuable insights into both traditional and contemporary approaches to climate change adaptation in sustainable seaweed farming [20].

2.2. Study Design

A cross-sectional approach was utilized for this study. This method facilitated the collection of primary data from participants in their residences. Respondents were presented with a researcher-designed questionnaire to gather information about seaweed farming and climate change. This design was deemed appropriate as it allowed for data collection at a single point in time using various methods, proving to be both cost-effective and time-efficient.

2.3. Target Population

The study focused on seaweed farmers from Chwaka, Uroa, and Marumbi villages (see Figure 1). According to the Shehia's register (2022), there were 1500 seaweed farmers in Chwaka, 700 in Uroa, and 369 in Marumbi, totaling 2569 individuals who constituted the target population. Both male and female farmers were included. These participants were selected due to their direct involvement in seaweed cultivation, making them ideal sources of relevant information for the study's objectives.

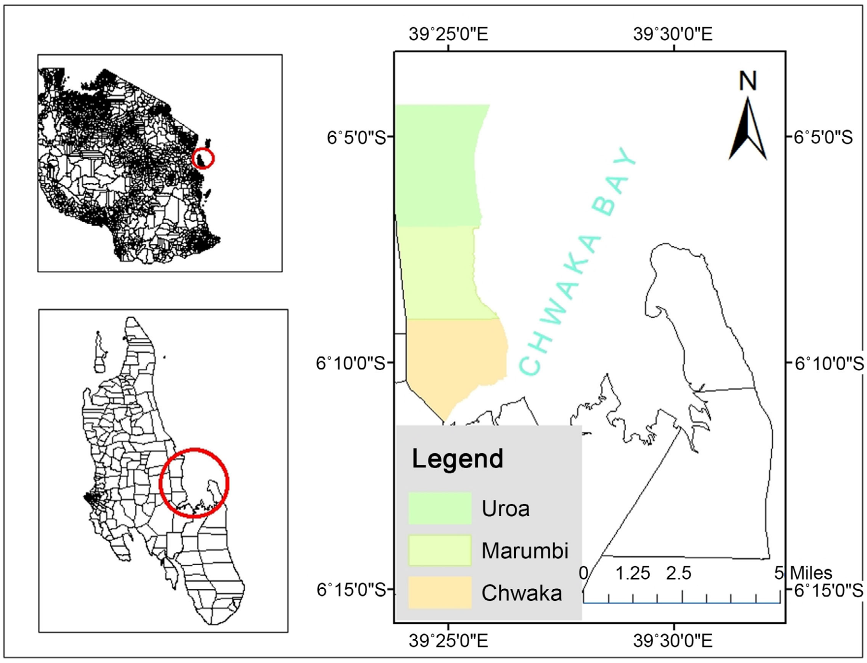

Figure 1. Location of study sites.

2.4. Sample Size Determination

As defined by [21], a sample size represents a specific number of respondents drawn from a given population. It refers to the process by which the researcher selects items for the sample. Given the large target population, it was neither feasible nor necessary to include all individuals. Therefore, determining a representative sample was crucial. The sample size for this study was calculated using the formula proposed by [22], as outlined below:

$$n = \frac{N}{1 + N(e)^2}$$

where n = sample size, N = Total seaweed farmers and e = level of precision (5%)

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$$n = \frac{N}{1 + N(e)^2}$$

$$n = \frac{2569}{1 + 2569(0.05)^2}$$

The sample size was $n = \frac{2569}{7.422} = 346$. Population, sample size (respondents) and their location is summarized in **Figure 2**.

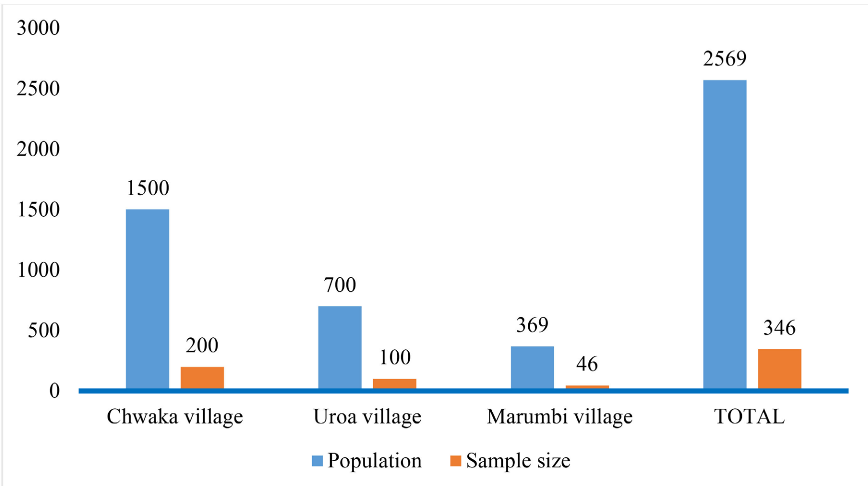

Figure 2. Seaweed farmers' sampling distribution. Source: Research data (2023).

2.5. Sampling Methodology

Sampling involves selecting a representative subset of a population to determine characteristics of the entire group [23]. This study employed stratified sampling, a statistical technique that ensures representative samples by dividing the population into distinct subgroups, or strata. The researcher segmented villages into strata, treating each as an independent mini-population. Subsequently, simple random sampling was utilized to select respondents from each stratum.

2.6. Data Gathering Methods

The research incorporated both primary and secondary data sources. Primary data was collected in the field using questionnaires and key informant interviews, while secondary data was obtained through reviewing relevant literature.

2.7. Questionnaire Design

Respondents were provided with adequate time for reflection prior to completing the questionnaires. The survey instruments contained structured items to facilitate tabulation and analysis. A questionnaire survey was administered to 346 seaweed farmers, featuring close-ended questions where participants were required to indicate their responses in designated spaces. The questionnaire gathered information related to various subcomponents.

2.8. Interview Process

The study employed a flexible approach to interviewing, allowing for restructuring as necessary, in accordance with typical survey practices [21]. Structured interviews were conducted with five executive officers from different institutions, including an expert from the Ministry of Fisheries and Livestock, to elicit crucial information and perspectives. The interviews explored the interactions among farmers regarding seaweed farming activities and empowerment. Information was also collected on the availability of seaweed tools and cost regulations.

2.9. Data Analysis Techniques

Questionnaire data underwent statistical analysis using descriptive methods, facilitated by Statistical Package for Social Sciences (SPSS) version 23 for coding. SPSS enabled the researcher to generate visual representations such as charts, graphs, and tables, including response frequencies from different respondent categories. Interview data was analyzed using the content analysis method.

3. Results and Discussion

3.1. Survey Participation

The research distributed 235 (60%) questionnaires, all of which were completed and analyzed. Additionally, 111 (40%) individuals participated in interviews, providing valuable insights pertinent to the study topic.

3.2. Participant Demographics

Examining respondent characteristics was essential for assessing data quality. This section delineates key demographic information, including gender, age, and field experience.

3.3. Gender Distribution

Gender, a significant factor in various domains, can be influenced differentially by social and economic phenomena. This study examined gender as a variable. The majority of participants were female (83%), with males comprising 17% (**Figure 3**). This finding suggests that women predominated in seaweed farming in the study areas, aligning with Sustainable Development Goals aimed at women's empowerment and poverty reduction.

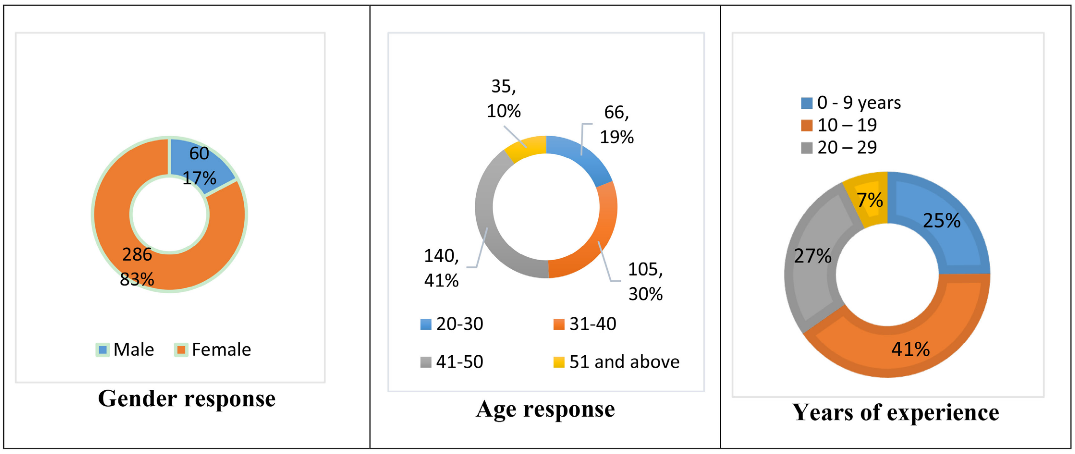

Figure 3. Demographic charts. Source: Research data (2023).

3.4. Age Composition

Respondent age was a vital characteristic investigated for its potential impact on responses. Age often reflects maturity and perspective on specific issues, rendering it an essential factor to consider. The largest age group was 41 - 50 years (41%), while those 51 and older represented 10%. This indicates that the seaweed farming sector primarily employed individuals aged 41 - 50, consistent with government plans to reduce poverty in this age bracket. This group is characterized by motivation and workplace assertiveness.

3.5. Seaweed Farming Experience

The study also analyzed respondents' years of experience in seaweed farming, an important factor influencing the collected responses. Figure 3 illustrates the distribution of experience among participants. Data analysis reveals that the majority of respondents (41%) had 10 - 19 years of experience in seaweed farming. A smaller portion (7%) had 30 or more years of experience. This suggests that many seaweed farmers in the selected villages were committed to this activity long-term. The prevalence of farmers with approximately 20 years of experience implies that, under consistent conditions, farmers in the three selected villages tended to persist in seaweed farming. Long-term engagement also suggests that farmers perceived themselves as valued, recognized, and adequately compensated for their work. These findings align with existing literature and previous empirical studies.

3.6. Seaweed Farmers' Strategies for Adapting to Climate Change

A set of indicators was provided, enabling respondents to select the most appropriate response based on their experiences. Descriptive statistical methods were utilized to analyze various indicators of climate change adaptation strategies, and the results were presented.

3.6.1. Understanding of Climate Change Concept

The study revealed that a substantial proportion (61.7%) of respondents exhibited a high level of familiarity with the climate change concept. Furthermore, 23% demonstrated moderate familiarity, while 15.3% reported no familiarity (Figure 4). These findings suggest that the majority of seaweed farmers in the selected villages possessed knowledge of climate change. The results are consistent with research conducted by [24], which similarly identified a considerable level of climate change awareness among seaweed farmers. Both studies indicate a consistent understanding of climate change among seaweed farmers in the selected regions.

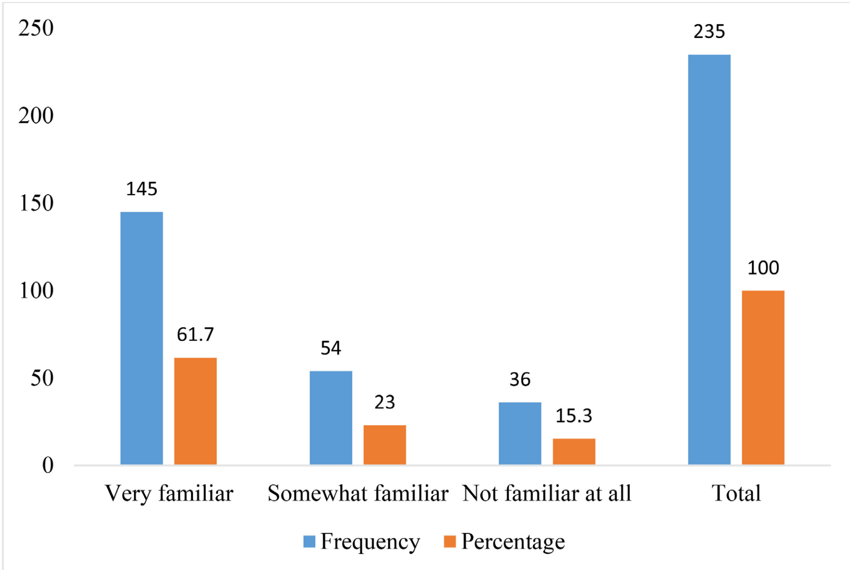

Figure 4. Familiarities with the concept of climate change. Source: Research data (2023).

3.6.2. Climate-Related Obstacles in Seaweed Cultivation

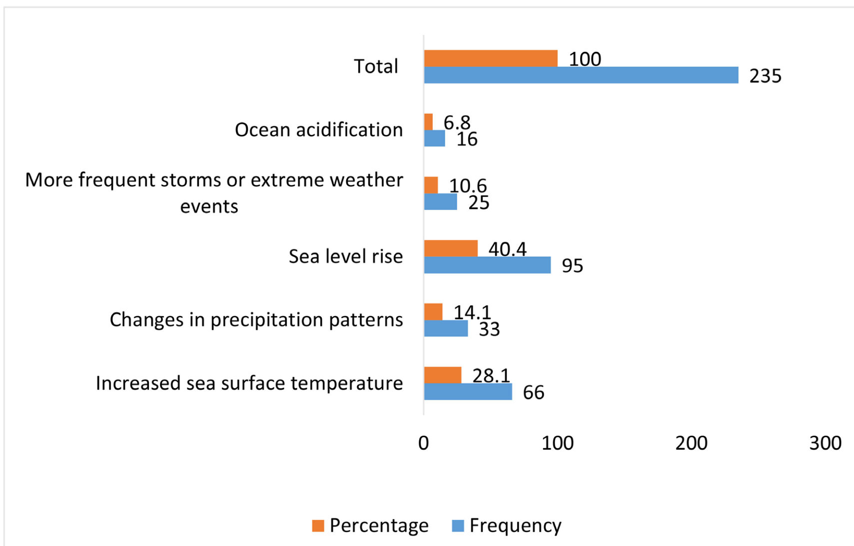

Figure 5. Climate-related challenges encountered in seaweed farming activities. Source: Research data (2023).

The research identified sea level rise as the primary climate-related challenge encountered by seaweed farmers, with 40.4% of respondents reporting it as an issue. Increased sea surface temperature emerged as the second most significant challenge, reported by 28.1% of respondents. Other challenges were not found to be as prevalent, as illustrated in **Figure 5**. This indicates that the majority of seaweed farmers in the selected villages have experienced sea level rise as a major climate-related obstacle in their cultivation activities. These findings corroborate the results of studies conducted by [25] [26]. Both this study and the previous research demonstrate that seaweed farmers in the chosen locations predominantly identify sea level rise as a significant climate-related challenge in their cultivation practices.

3.6.3. Climate Change Adaptation Strategies Employed in Seaweed Farming

Survey results revealed that the primary adaptation strategy utilized by seaweed farmers to address climate change challenges was the modification of farming techniques, accounting for 48.9% of respondents. This was followed by alterations in cultivation practices (27.7%) and implementation of infrastructure changes (23.4%), as shown in **Table 1**. These findings suggest that the majority of seaweed farmers in the selected villages have adopted novel farming techniques to address climate-related challenges in their operations. This observation aligns with researches conducted by [27]-[29].

Table 1. Specific adaptation strategies implemented to address climate change challenges

Adaptation Strategies	Frequency	Percentage
Changes in farming techniques	115	48.9
Changes in infrastructure	55	23.4
Changes in cultivation practices	65	27.7
Total	**235**	**100.0**

Source: Research data (2023).

3.6.4. Current Adaptation Approaches

Seaweed farmers reported implementing various adaptation strategies, including modifications to cultivation methods, species diversification, and relocation of farms. During interviews, participants noted, "We have been compelled to adjust our planting and harvesting practices due to changing water temperatures. We are also cultivating multiple seaweed species to mitigate risks, as some exhibit greater resilience to temperature fluctuations and diseases. This diversification not only aids in adaptation but also creates new market opportunities." Some respondents also mentioned relocating their farms, stating, "We have considered moving our operations to areas with more favorable water conditions. While it is a significant undertaking, it has become necessary to protect our crops from the negative impacts of warming waters." These findings are consistent with the study conducted by [30].

3.7. Effects of Modern and Traditional Seaweed Farming Methods

Respondents were asked to select from a list of statements regarding the impacts of using modern and traditional seaweed farming techniques. Descriptive statistical methods were employed to analyze the responses, and the results are presented below.

3.7.1. Acquaintance with Contemporary and Traditional Seaweed Cultivation Techniques

Table 2 indicates that the majority of participants (57.4%) were entirely unfamiliar with modern seaweed farming methods. A smaller proportion (23%) possessed some familiarity, while only 19.6% were well-versed in these techniques. This suggests that most seaweed farmers in the selected villages lack knowledge of contemporary cultivation practices. This observation aligns with studies by [31]-[33], which noted a comparable trend among their respondents, with a substantial number demonstrating limited awareness of modern seaweed farming approaches. Conversely, Table 2 reveals that a significant majority (69.4%) of respondents were highly familiar with traditional seaweed farming methods. An additional 27.6% possessed some familiarity, while a mere 3% were entirely unfamiliar. This indicates that most seaweed farmers in the chosen villages are well-acquainted with conventional cultivation techniques. This finding corroborates the research conducted by [34], which also noted widespread familiarity with traditional methods among participants. It further suggests that a considerable number of seaweed farmers in these areas possess a robust understanding of time-honored farming practices, echoing the conclusions of [35].

Table 2. Familiarities with the modern and traditional seaweed farming methods.

Parameters	Modern seaweed farming methods		Traditional seaweed farming methods	
	Frequency	Percentage	Frequency	Percentage
Very familiar	46	19.6	163	69.4
Somewhat familiar	54	23.0	65	27.6
Not familiar at all	135	57.4	7	3.0
Total	**235**	**100.0**	**235**	**100.0**

Source: Research data (2023).

3.7.2. Currently Employed Modern Seaweed Farming Techniques

The results demonstrate that the largest group of respondents (48.9%) utilized alternative modern seaweed farming methods. The second most prevalent approach was advanced cultivation techniques, adopted by 27.7% of farmers. Additionally, 14.9% of respondents employed integrated multitrophic aquaculture as their modern farming method, while 8.5% utilized automated monitoring systems (Figure 6). These findings suggest that the majority of seaweed farmers in the selected villages prefer modern farming methods other than those explicitly enumerated in this statement. This observation is consistent with the study conducted by [36], which also found that most seaweed farmers in the examined villages favored alternative modern farming techniques for seaweed cultivation.

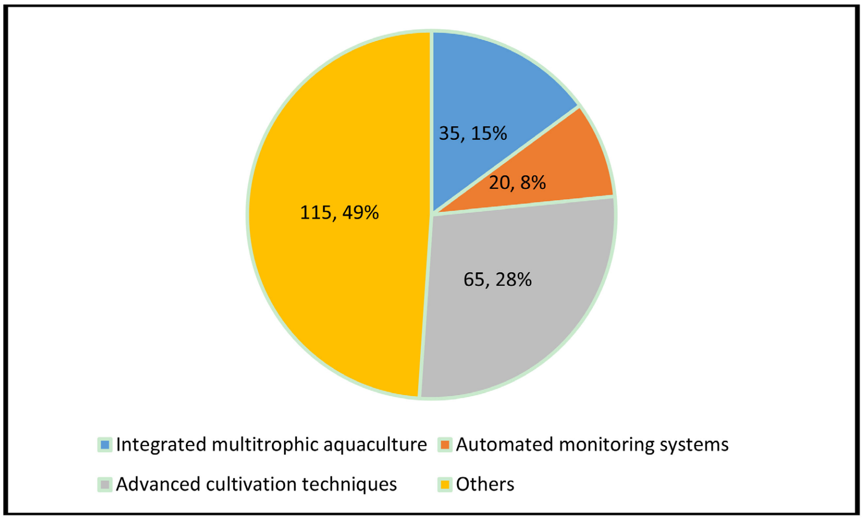

Figure 6. Modern seaweed farming methods currently used. Source: Research data (2023).

3.7.3. Conventional Seaweed Cultivation Techniques

The study revealed that the majority of participants (76.2%) employed hand-tying methods as their traditional seaweed farming technique. Raft-based cultivation was utilized by 14.9% of farmers, while 8.9% employed natural substrates (**Figure 7**). This indicates that hand-tying is the predominant traditional method among seaweed farmers in the selected villages. These findings align with research by [37], which noted that hand-tying is particularly prevalent among female farmers due to its suitability for weak ocean currents and its accessibility for individuals unable to swim.

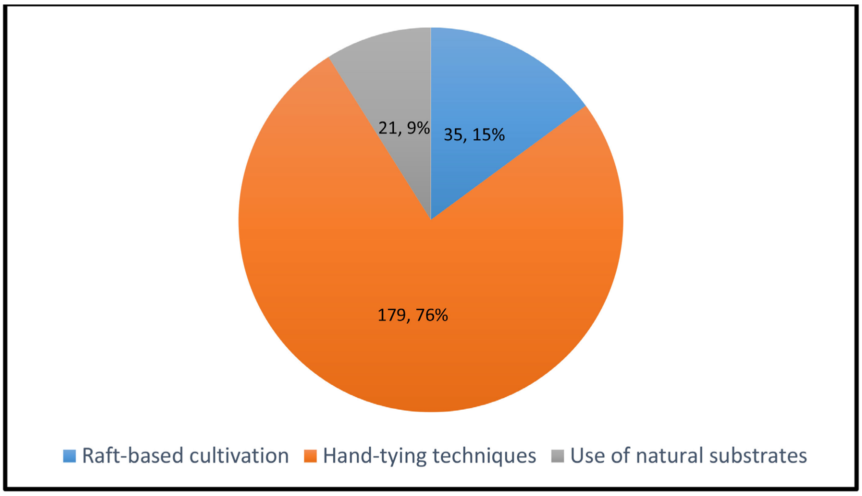

Figure 7. Traditional seaweed farming methods used. Source: Research data (2023).

3.7.4. Comparing Modern and Traditional Approaches

The research found that 53.2% (125) of respondents were uncertain whether modern seaweed farming methods yielded superior results compared to traditional techniques. Of the remaining participants, 27.7% (65) believed modern methods produced higher yields, while 19.1% (45) disagreed with this statement. This suggests that the majority of seaweed farmers in the studied villages were uncertain about the comparative productivity of modern and traditional methods (**Table 3**).

Table 3. Modern seaweed farming methods result in higher yields.

Parameters	Frequency	Percentage
Yes	65	27.7
No	45	19.1
Unsure	125	53.2
Total	**235**	**100.0**

Source: Research data (2023).

Regarding environmental sustainability, 83.4% (196) of respondents considered modern seaweed farming methods more sustainable than traditional approaches. An additional 14% (33) viewed both methods as equally sustainable, while only 2.6% believed modern techniques were less environmentally friendly (**Table 4**). This implies that the majority of seaweed farmers in the selected areas perceived modern methods as more environmentally sustainable. These findings are consistent with research by [38], which observed that rafting or floating methods tend to produce higher yields.

Table 4. Environmental sustainability of modern compared to traditional seaweed farming methods.

Parameters	Frequency	Percentage
More sustainable	196	83.4
Equally sustainable	33	14.0
Less sustainable	6	2.6
Total	**235**	**100.0**

Source: Research data (2023).

Farmers utilizing modern techniques, including specialized equipment and technology, reported increased yields and productivity. They noted that these methods allowed for improved management of environmental factors, resulting in more consistent and superior seaweed quality. Respondents emphasized that modern approaches enable farmers to achieve higher yields per cultivation area. Controlled conditions, such as water quality and temperature regulation, contribute to optimized growth rates and reduced losses. Some participants added that modern methods facilitate precise environmental control, ensuring uniform seaweed growth and quality. This aspect is particularly valuable for meeting commercial market demands, which often require consistent product quality.

Some respondents emphasized the significance of contemporary farming techniques, noting that these methods often incorporate risk management strategies. These include early identification of environmental stressors and the capacity to swiftly implement corrective measures, thereby reducing the likelihood of crop failures due to unforeseen circumstances. The integration of technology and automation can enhance the efficiency of various farming processes, decreasing the labor and time required for seaweed cultivation, harvesting, and processing. This increased efficiency can improve the economic viability of farming operations.

Conversely, farmers employing traditional or local methods reported lower yields, primarily due to limited access to resources and technology. These local approaches typically rely on natural conditions, which can be less predictable and less conducive to maximizing production. However, some farmers highlighted that certain markets prefer the taste and quality of seaweed grown using local methods. Many practitioners of local farming techniques prioritize sustainability, often utilizing polyculture methods that involve growing seaweed alongside other marine species. This approach can enhance ecosystem health by mitigating the environmental impact of monoculture farming [39] [40]. Additional respondents mentioned that specific markets, particularly those favoring traditional or artisanal products, may prefer seaweed cultivated using local methods. These products are often perceived as having distinct flavors and textures, appealing to niche markets. By avoiding synthetic chemicals and minimizing energy consumption, local methods contribute to marine ecosystem preservation. Furthermore, these approaches typically involve lower initial costs and maintenance expenses compared to modern techniques, making them more accessible to farmers with limited financial resources.

3.8. Awareness of Seaweed Climate Change and Sustainable Livelihoods

Respondents were presented with a list of statements containing various indicators and asked to select the most appropriate based on their perspectives. Descriptive statistical techniques were employed to analyze different indicators of awareness regarding seaweed, climate change, and sustainable livelihoods. The results are presented in **Table 5**. The findings revealed that the majority (145) of respondents, constituting 61.7%, were unaware of seaweed's role in mitigating climate change impacts. Only 90 (38.3%) of respondents demonstrated awareness of this role. This implies that most seaweed farmers participating in cultivation activities in the selected villages were unaware of seaweed's potential to mitigate climate change impacts. In contrast, a significant majority of respondents (228, or 97%) were aware of seaweed farming's potential to provide sustainable livelihoods for coastal communities, while only 3% of respondents lacked this awareness (**Table 5**). This finding suggests that the vast majority of seaweed farmers engaged in cultivation activities in the selected villages recognized the potential of seaweed farming to offer sustainable livelihoods for coastal communities.

Table 5. Indicators of awareness of seaweed climate change and sustainable livelihood.

Parameter	Number of Respondents	
	YES	NO
Role that seaweed plays in mitigating the impacts of climate change	90	145
Potential of seaweed farming to provide sustainable livelihoods for coastal communities	228	7
Participation in any workshops, seminars, or educational programs related to seaweed cultivation, climate change, or sustainable livelihoods	127	108
Importance of increasing awareness of the connections between seaweed, climate change, and sustainable livelihoods	218	17

Source: Research data (2023).

Furthermore, 54% of respondents have participated in workshops, seminars, or educational initiatives focused on seaweed cultivation, climate change, or sustainable livelihoods, while 46% have not. This indicates a nearly equal distribution between participants and non-participants in such programs among seaweed farmers in the selected villages. Additionally, the majority of respondents (92.8% or 218 individuals) consider it important to increase awareness about the connections between seaweed, climate change, and sustainable livelihoods, whereas only 7.2% (17 respondents) do not, as shown in Table 5.

Another aspect examined was the understanding of seaweed's potential to absorb carbon dioxide and mitigate ocean acidification. The results reveal that 53.2% of respondents had no knowledge about this potential, 14% were moderately knowledgeable, and 32.8% were very knowledgeable (Figure 8).

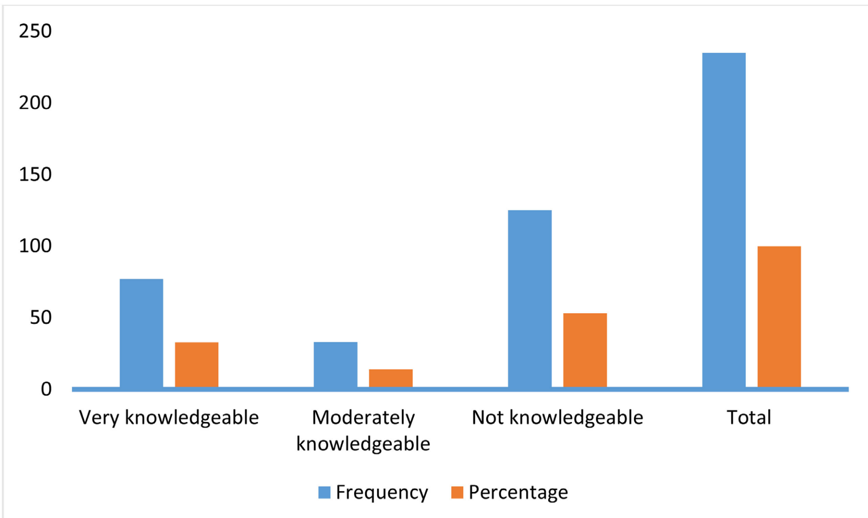

Figure 8. Knowledge about the potential of seaweed to absorb carbon dioxide and reduce ocean acidification. Source: Research data (2023).

These findings indicate that the majority of seaweed farmers in the selected villages lack knowledge about seaweed's capacity to absorb carbon dioxide and reduce ocean acidification. However, a small number of interviewees demonstrated a basic understanding of seaweed's role in climate change mitigation. They recognized that seaweed, particularly macroalgae, absorbs CO_2 during photosynthesis, potentially contributing to the reduction of greenhouse gas emissions. Participants noted that seaweed incorporates atmospheric carbon into its biomass, effectively removing CO_2 from the environment and contributing to climate change mitigation. Farmers and coastal community members expressed concerns about climate change impacts on seaweed farming, citing rising sea temperatures, ocean acidification, and extreme weather events as challenges. This aligns with research by [39] [40], which describes climate change's negative impact on seaweed production, as increasing seawater temperatures can induce seaweed diseases. Interviewees mentioned that warmer waters could stress seaweed, potentially causing bleaching, reduced growth rates, altered reproduction timing, and changes in seaweed community composition. These observations correspond with a study by [41], which found that the majority of village seaweed farmers are aware of climate changes and their impacts.

While this study mentions the economic importance of seaweed farming, other studies suggest that the economic ramifications of climate change are anticipated to be far-reaching, affecting various industries and regions worldwide. While some areas may experience benefits, others are likely to face substantial economic losses [42] [43]. In the United States, sectors such as agriculture and forestry might see economic advantages, whereas energy, coastal infrastructure, and water resources could suffer negative impacts [43]. European households could experience annual welfare losses ranging from 0.2% - 1% by the 2080s due to market impacts, with significant regional disparities. Southern Europe, the British Isles, and Central Europe North appear most vulnerable, while Northern Europe might experience net economic gains, primarily in agriculture [42]. Notably, there are discrepancies in the projected outcomes across different studies. Some research indicates potential gains in certain sectors [43], while other studies emphasize overall negative consequences, particularly for vulnerable and marginalized groups [44]. Furthermore, poor countries are expected to bear a disproportionate burden of the economic impacts, largely due to their geographical location in low latitudes with already high temperatures [45]. Therefore, the economic effects of climate change are multifaceted and diverse. Although some regions and sectors may benefit, the overall global impact is predicted to be negative, with developing nations facing the most severe consequences [45]. The intensity of these impacts can be significantly influenced by mitigation efforts and socioeconomic development trajectories [46]. To address these challenges, a comprehensive approach incorporating both preventive and corrective measures is crucial to enhance resilience and alleviate financial constraints, especially for smaller nations [47]

4. Conclusion

The seaweed farmers of Zanzibar have historically relied on traditional knowledge to navigate the complexities of seaweed cultivation. Their profound understanding of the coastal ecosystem, comprehensive grasp of tidal patterns, and proficiency in selecting appropriate species have been instrumental in adapting to climate fluctuations. Furthermore, the integration of contemporary knowledge, encompassing scientific research and technological advancements, has propelled the industry towards sustainability. Enhanced cultivation methods, disease control strategies, and quality assurance measures have resulted in increased productivity and improved product standards. However, Zanzibar's seaweed farming industry now faces increasing climate-related challenges, including elevated sea temperatures, altered precipitation patterns, and severe weather events. These disruptions threaten the industry's stability and the economic well-being of coastal populations. The study emphasizes the importance of integrating local and modern knowledge. This synthesis enables Zanzibar's seaweed farmers to adapt to changing environmental conditions while preserving cultural heritage and promoting environmental stewardship. The sustainable seaweed farming practices in Zanzibar exemplify the resilience of coastal communities and demonstrate the potential for a balanced coexistence between local traditions and modern knowledge. In conclusion, the concerns expressed by farmers and coastal communities underscore the urgent need to address climate change impacts on seaweed farming. Addressing these challenges necessitates a comprehensive approach, incorporating adaptation strategies, policy support, scientific research, and community resilience-building initiatives to ensure the long-term viability of the seaweed farming sector.

5. Recommendations

By implementing the following recommendations, Zanzibar can establish a more climate-resilient, sustainable, and thriving future for its seaweed farmers and the marine ecosystems they depend on. In the context of climate change, the integration of traditional and modern approaches is not merely a strategy; it serves as a source of hope and inspiration for all stakeholders.

1) The government should facilitate regular knowledge-sharing sessions among seaweed farmers to exchange climate change adaptation strategies, fostering a collaborative learning environment.

2) Seaweed farmers should recognize and maintain traditional adaptation methods that have proven effective, such as cultivating select seaweed species and modifying planting schedules based on local climate indicators.

3) The government should provide training programs and resources to promote climate-resilient farming practices, including disease-resistant seaweed varieties and effective pest management techniques.

4) The government should advocate for the adoption of modern, sustainable seaweed farming techniques, such as integrated multi-trophic aquaculture (IMTA) systems, while respecting and maintaining traditional practices that have minimal ecological impact.

5) The government should develop educational programs and workshops focused on climate change impacts specific to seaweed farming. These should be aimed at seaweed farmers and their communities to enhance their understanding of climate-related challenges.

6) The study focuses solely on three villages within one bay in Zanzibar, limiting the generalizability of findings to other regions or seaweed farming contexts. The findings may not be representative of seaweed farming practices or climate change impacts across broader geographic areas. Therefore, there is a need for further investigation to other coastal areas of Zanzibar (both Unguja and Pemba Islands) to get wider views of the topic.

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Conflicts of Interest

The authors declare no conflicts of interest.

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