



## Adaptation Strategies to Climate Change in Coastal Communities of Ambon City, Indonesia

Pieter T. Berhиту\*, Aryanto Boreel, Atris G. Pattiasina

Department of Urban and Regional Planning, Faculty of Engineering, Pattimura University, Ambon - Indonesia

\*Corresponding author: [pieter.berhиту@lecturer.unpatti.ac.id](mailto:pieter.berhиту@lecturer.unpatti.ac.id)

### ARTICLE INFO

#### Article History:

Received: Feb. 10, 2025

Accepted: March 25, 2025

Online: April 8, 2025

#### Keywords:

Adaptation  
Climate change,  
Coastal communities,  
Mitigation strategies,  
Sustainability

### ABSTRACT

Climate change has significantly impacted coastal communities in Ambon City, leading to coastal erosion, tidal flooding, and declining fish catches. This study analyzed adaptation strategies employed by coastal communities using a socio-ecological approach. The research employed a qualitative case study method, including field observations, in-depth interviews, and geospatial analysis. Data were collected from several coastal areas in Ambon City and were analyzed using the Social-Ecological System (SES) model to understand community adaptation patterns. The findings revealed that communities implement three main adaptation strategies: (1) physical adaptation, such as constructing seawalls and rehabilitating coastal ecosystems; (2) economic adaptation through livelihood diversification, including ecotourism and small-scale enterprises; and (3) social adaptation, involving institutional strengthening and environmental education. The integration of technology, such as early warning systems and ecology-based aquaculture, plays a crucial role in enhancing community resilience. Collaboration among communities, the government, and other stakeholders is essential for developing more sustainable adaptation policies. This study recommends a more holistic, community-based approach to strengthen the resilience of coastal communities in Ambon City against the ongoing impacts of climate change.

### INTRODUCTION

Climate change has become a global challenge with far-reaching impacts on the environment and human livelihoods, particularly in coastal areas (Badjeck *et al.*, 2010; Shawket *et al.*, 2019). Rising global temperatures, shifting rainfall patterns, and the increasing frequency and intensity of natural disasters have accelerated coastal ecosystem degradation and threatened the communities that depend on them (Brander, 2010; Wang *et al.*, 2016). As a coastal city in Indonesia, Ambon faces high climate change-related risks, including coastal erosion, seawater intrusion, and more frequent tidal flooding (Wattimena *et al.*, 2019; Latumeten *et al.*, 2023; Sirahitu *et al.*, 2023). Additionally, uncontrolled land-use changes have further exacerbated coastal ecosystem degradation (Berhиту & Kalalimbong, 2009). Unplanned development activities disregarding environmental carrying capacity have led to the conversion of coastal areas into

residential zones, industrial sites, and public infrastructure. Consequently, ecosystem balance has been disrupted, leading to environmental degradation and increasing community vulnerability to disasters (**Rahman *et al.*, 2020a; Nopiana *et al.*, 2024**).

Coastal communities in Ambon Municipality are experiencing various negative impacts due to climate change and environmental degradation. The decline in fishery resources affects fishers, while the increasing frequency of disasters heightens economic and social uncertainty (**Coulthard, 2008; Ohwayo *et al.*, 2016**). Without effective adaptation strategies, these conditions could further deteriorate the well-being of coastal communities (**Asch *et al.*, 2007**). Research has shown that community adaptation to climate change requires a Social-Ecological System (SES) approach, which holistically considers social, economic, and institutional factors (**Salgueiro-Otero & Ojea, 2020; Hossain *et al.*, 2023**). Previous studies also indicate that successful adaptation is influenced by access to information, education levels, and support from governments and local organizations (**Giupponi *et al.*, 2022; Malakar *et al.*, 2023; Kanan & Giupponi, 2024**). Furthermore, recent research highlights the importance of integrating technology and traditional knowledge in building coastal community resilience (**Nawari *et al.*, 2023**).

This study introduced a novel approach by developing a community-based adaptation model that deeply integrates socio-ecological aspects. Unlike previous studies that predominantly focus on disaster mitigation or economic aspects, this research emphasized the interaction between social, economic, and environmental factors in shaping effective and sustainable adaptation strategies. By doing so, this study aimed to provide more applicable and context-specific policy recommendations for coastal communities in Ambon City.

Based on this background, the study aimed to address key research questions: (1) How do coastal communities in Ambon respond to climate change impacts and coastal land-use changes?; (2) What factors influence the effectiveness of the adaptation strategies implemented?, and (3) How can a community-based adaptation model be developed to enhance the long-term resilience of coastal communities?. To answer these questions, this research aimed to (a) identify the adaptation strategies currently employed by coastal communities in Ambon, (b) analyze the factors influencing adaptation success, and (c) design a locally relevant, community-based adaptation model.

The findings of this study are expected to contribute to the development of more effective and evidence-based climate change adaptation policies. In addition to its academic value in advancing socio-ecological adaptation theory in the context of climate change, this research has practical implications for local governments, community organizations, and other stakeholders in designing more inclusive and sustainable adaptation strategies for Ambon City and other coastal regions in Indonesia.

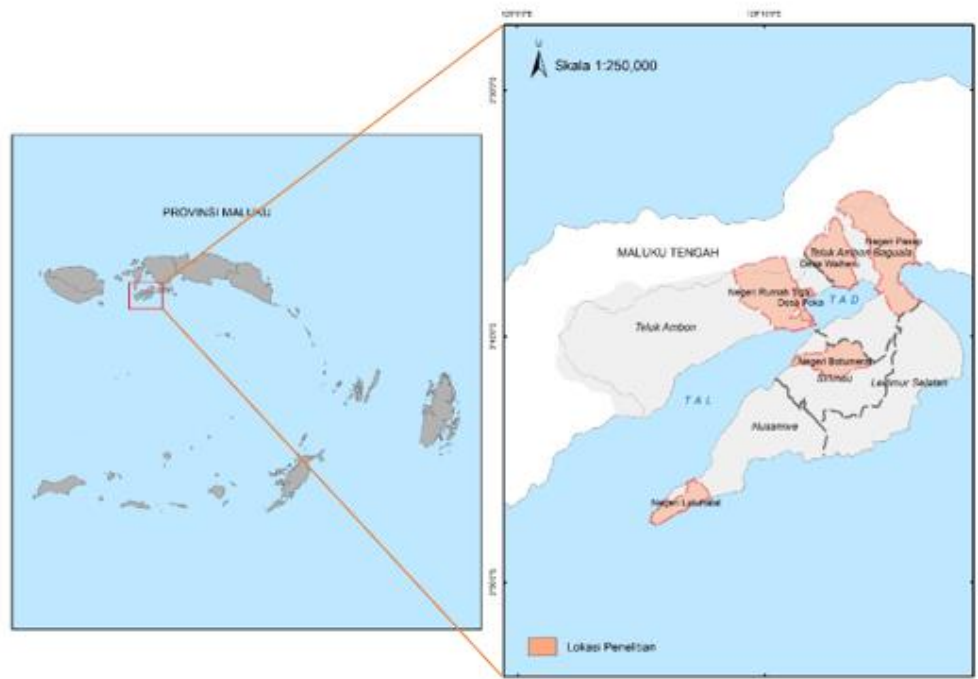
## MATERIALS AND METHODS

### Research design and study location

This study employed a qualitative approach using a case study method to understand the adaptation strategies of coastal communities in Ambon City in response to climate change and land-use changes. The case study method was chosen as it allows for an in-depth exploration of complex socio-ecological phenomena within a specific context.

The research was conducted over a one-year in 2024 in the coastal areas of Ambon City. The study locations included the Outer Ambon Bay (TAL) and Inner Ambon Bay (TAD) (Fig. 1), which have experienced coastal ecosystem changes due to climate change and developmental activities. Purposive sampling was used to select study sites based on their ecological characteristics and significant land-use dynamics.

Several villages (negeri/desa/kelurahan) were selected as research sites, including Negeri Latuhalat, Eri, Laha, Tawiri, and Negeri Rumahtiga in the Outer Ambon Bay (TAL) region, as well as Desa Galala, Negeri Hative Kecil, Halong, Kelurahan Lateri, Negeri Passo, Desa Waiheru, and Desa Poka in the Inner Ambon Bay (IAB) region. These areas were chosen due to their high vulnerability to climate change and coastal land-use changes, as well as the diverse adaptation strategies implemented by local communities (Pical & Rahman, 2025).



**Fig. 1.** Map of study sites

### Data sampling

This study collected both primary and secondary data. Primary data were obtained through field observations, in-depth interviews, and geospatial analysis using machine

learning technology on the Google Earth Engine (GEE) platform. Field observations were conducted to identify land-use changes over the past two decades (2004–2024) and to directly examine the impacts of climate change on coastal communities. In-depth interviews were carried out with various community groups, including fishers, aquaculture farmers, community leaders, and other key stakeholders. These interviews aimed to explore local experiences, perceptions, and adaptation strategies in response to climate change. Respondents were purposively selected based on their engagement in coastal activities and their experience in dealing with environmental changes.

Secondary data were sourced from official institutions, such as the Central Bureau of Statistics (BPS) of Ambon City, the Regional Development Planning Agency, and relevant previous studies. These data included demographic information, administrative boundaries, road and river networks, and environmental data related to climate change and land-use dynamics.

### Data analysis

The collected data were analyzed using a qualitative approach based on the Social-Ecological System (SES) framework. Observation and interview data were analyzed to identify emerging adaptation patterns within the community. Geospatial analysis using Google Earth Engine (GEE) was conducted to map coastal land-use changes over the past two decades. The integration of qualitative and geospatial data aimed to provide a comprehensive understanding of the relationship between ecological changes and the socio-economic adaptation strategies of coastal communities in Ambon City.

## RESULTS AND DISCUSSION

### Characteristics of coastal communities

The coastal communities of Ambon City exhibit distinctive characteristics shaped by their long-standing interaction with the maritime environment over centuries. Their primary dependence on marine resources has forged a strong identity as fishing communities, characterized by robust social systems based on cooperation and communal solidarity (**Berkes *et al.*, 2000**). These values are reflected in various activities, such as collective fishing practices, mutual assistance in house construction, and traditional ceremonies that strengthen social cohesion.

Beyond social aspects, Ambon's coastal communities also possess extensive traditional ecological knowledge of the sea, including ocean currents, fish migration seasons, and local climate variability (**Pical *et al.*, 2024; Tuapetel & Rahman, 2025**). However, climate change and environmental degradation have increasingly impacted their livelihoods, leading to uncertainties in fishery resources and heightened risks of coastal disasters (**Pical & Rahman, 2025**).

### Age and Length of residency

An individual's age and duration of residence in a particular area influence their understanding of and response to environmental changes. According to this study, the ages of coastal community respondents in Ambon City range from 15 to 64 years, with the majority (95%) falling within the productive age group. Most respondents (90%) have lived in coastal areas for more than 20 years, indicating extensive experience in navigating environmental changes.

Several studies suggest that older age groups tend to perceive climate change risks as lower, as they view environmental changes as part of natural cycles (**Assis *et al.*, 2023**). In contrast, younger generations are more actively engaged in advocacy and responses to climate change, particularly in promoting mitigation and adaptation policies (**Moser & Ekstrom, 2010**).

### Education level

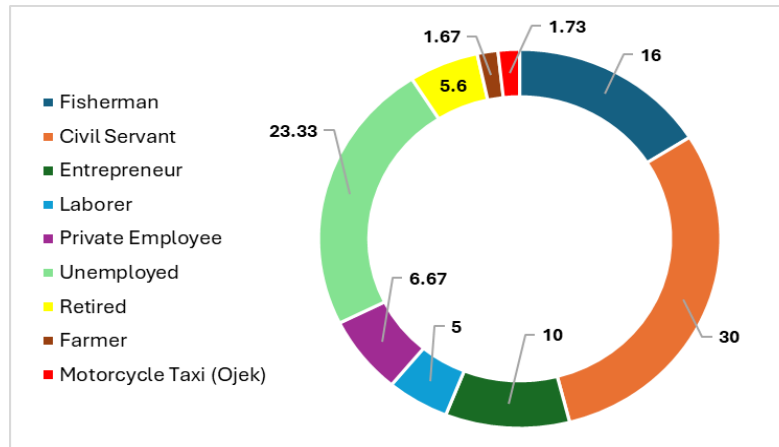
Education plays a crucial role in enhancing the adaptive capacity of coastal communities in response to environmental changes (**UNESCO, 2017**). This study found that most respondents (71.67%) had completed primary to secondary education (elementary 60%, medium 8.3%, and high school 3.37%), while 28.33% had attained higher education (undergraduate 23.3% and postgraduate degrees 5.0%).

A higher level of education contributes to increased awareness and understanding of climate change, as well as the ability to adopt science-based adaptation strategies (**Adger *et al.*, 2009**). However, among coastal communities with lower education levels, adaptation strategies often rely on empirical experience and traditional knowledge. While valuable, these approaches may have limitations in addressing the growing complexities of environmental changes (**McNamara & Westoby, 2011**).

### Livelihoods

Many coastal communities in Ambon City still rely on the fisheries sector as their primary source of livelihood. This study found that 16% of respondents work as fishers, while 30% are employed as civil servants. The remaining respondents are engaged in various occupations, including entrepreneurship (10%), labor work (5%), private-sector employment (6.67%), and other professions (Fig. 2).

The high dependence on the fisheries sector makes coastal communities highly vulnerable to the impacts of climate change and environmental degradation. Declining fish catches due to rising sea temperatures and coastal habitat degradation have prompted some community members to diversify their income sources, shifting to sectors such as tourism, small businesses, and trade (**Badjeck *et al.*, 2010**). However, this transition requires strong policy support to ensure that alternative livelihoods remain sustainable in the long term (**Bennett *et al.*, 2014**).



**Fig. 2.** Occupational distribution of coastal communities in Ambon

Compared to coastal areas such as those in Java or Sulawesi, where the fisheries sector often accounts for 40–50% of total livelihoods (Saputra *et al.*, 2021), the percentage of fishers in this region is relatively lower. In some coastal areas of Eastern Indonesia, such as East Nusa Tenggara, the agricultural sector is more dominant than services and entrepreneurship (Susanto *et al.*, 2020). In contrast, only 1.67% of respondents in this study were farmers. This indicates that the coastal communities in the study area have a more diverse economic structure compared to traditional coastal regions that primarily depend on fisheries.

### Income levels

The income levels of coastal communities in Ambon City exhibit considerable variation. The study found that 56.67% of respondents earn below the 2024 municipal minimum wage (UMK) of IDR 2,991,299. Only 18.33% of respondents reported earning above this threshold, while 25% had irregular income.

Low income often limits access to adaptive technologies and financial services that could enhance resilience to climate change (Barbier, 2010). Moreover, low-income households tend to prioritize daily basic needs, making environmental concerns a lower priority (Adger, 2003). Therefore, community-based adaptation strategies must consider economic factors to ensure active participation in environmental mitigation and adaptation efforts.

The income levels of coastal communities are strongly influenced by their occupations. The study found that most residents work as civil servants, followed by fishers, entrepreneurs, laborers, and private sector employees. Additionally, some respondents were unemployed, retired, farmers, or motorcycle taxi drivers. This occupational composition reflects a diversified livelihood structure in coastal communities, extending beyond the fisheries sector to include services, agriculture, and government employment.

Income variability is particularly evident among different occupations. Fishers, for instance, experience highly fluctuating earnings depending on the season, fish availability, and weather conditions (**BPS, 2023**). A study by **Widodo and Purwanti (2022)** found that the average income of fishers in various coastal regions in Indonesia ranges from IDR 2,500,000 to IDR 4,500,000 per month, depending on fishing gear type and location. In contrast, civil servants and formal sector workers generally have more stable incomes than informal workers such as laborers and small-scale fishers.

Comparisons with other coastal regions in Indonesia highlight income disparities. For instance, research by **Yusuf and Wahyuni (2021)** in South Sulawesi found that economic diversification plays a crucial role in improving coastal community welfare. Households engaged in supplementary businesses, such as seafood trade and tourism services, tend to have higher incomes than those relying solely on capture fisheries. This aligns with findings by **Susilowati and Ruchimat (2020)**, which indicate that household economic resilience among fishers in Java and Sumatra is stronger in communities that have developed additional business sectors.

Beyond occupation and economic diversification, market access and infrastructure significantly influence income levels. **Fauzi (2019)** noted that regions with good transportation connectivity tend to have higher incomes due to easier distribution of fishery products and broader market access. Conversely, remote areas with limited infrastructure face challenges in marketing their catch, leading to lower fisher incomes.

Structural poverty remains a challenge for coastal communities. **Kusnadi (2019)** highlighted that many small-scale fishers are trapped in a cycle of poverty due to limited access to capital, technology, and business support. As a result, they struggle to improve productivity and market competitiveness.

Community-based economic development is a viable strategy for improving coastal community welfare. **Rianse and Abdi (2021)** emphasized that group-based empowerment programs, such as fisher cooperatives and skills training, can enhance economic self-reliance. Additionally, strengthening policies that support small-scale fishers and micro-enterprises is essential for fostering economic growth in coastal areas.

Enhancing the welfare of coastal communities requires a holistic approach. Efforts should focus not only on improving access to capital and markets but also on promoting livelihood diversification, skill development, and sustainable economic policies. Therefore, sustainable coastal resource management strategies must be developed to ensure that coastal communities can derive optimal economic benefits from their resources while maintaining long-term environmental resilience.

### **Impact of climate change**

The impact of climate change presents significant challenges for coastal communities, including those in Ambon City. One of the primary effects is sea level rise, which leads to coastal erosion and tidal flooding. These phenomena threaten coastal infrastructure, settlements, and livelihoods dependent on marine resources. According to

**Anjani *et al.* (2023)**, climate change also contributes to increasingly unpredictable weather patterns, heightening the risk of hydrometeorological disasters in coastal areas.

Furthermore, climate change affects marine ecosystems, particularly coral reefs, which undergo bleaching due to rising sea temperatures and changes in seawater aragonite levels (**Cheung *et al.*, 2009**). This process weakens reef structures, making them more fragile and susceptible to degradation (**Berhиту & Kalalimbong, 2009**). The deterioration of coral reefs leads to a decline in marine biodiversity, including fish populations that serve as a primary source of income for local fishers.

Fishers in Ambon City face various challenges due to climate change, including an increased frequency of storms and strong winds that disrupt fishing activities. Consequently, they are often forced to reduce their fishing days, directly impacting their income. **Assis *et al.* (2023)** found that in such situations, fishers tend to seek alternative income sources, though these options often do not provide stable economic security.

Beyond the fisheries sector, climate change also affects freshwater availability. Altered rainfall patterns have led to prolonged dry seasons, making access to freshwater increasingly difficult. This issue extends to coastal agriculture, where seawater intrusion degrades soil fertility and reduces agricultural productivity (**Rahmawati *et al.*, 2023**).

Over the past two decades, Ambon's coastal ecosystems have experienced significant degradation. Large-scale coastal reclamation, declining mangrove cover, and increasing marine pollution have exacerbated the impacts of climate change (Fig. 3). The loss of mangrove forests, which serve as natural buffers against erosion and tidal flooding, has accelerated shoreline erosion and heightened disaster risks for coastal communities (**Sodikin *et al.*, 2023**).

The socioeconomic impacts of climate change are also profoundly felt. Coastal communities experience declining incomes as the fisheries and agricultural sectors are directly affected. Many fishers are forced to take on informal jobs with unstable earnings (**Pical & Rahman, 2025**). This situation presents new challenges in social welfare, including rising poverty levels and reduced access to essential services such as education and healthcare (**Anugraha *et al.*, 2022**).

Given these widespread impacts, mitigation and adaptation efforts are crucial in addressing climate change in coastal areas. Effective strategies include protecting coastal ecosystems, strengthening adaptive infrastructure, and enhancing community awareness and capacity to cope with environmental changes. Additionally, collaboration among local communities, government agencies, and stakeholders is essential in developing sustainable solutions to minimize the adverse effects of climate change in Ambon City (**Steven *et al.*, 2020**).





**Fig. 3.** Impacts of coastal ecosystem changes: (a) Marine debris that is retained in mangrove areas; (b) Damage to seawater retaining talud due to large waves and floods; (c) Rob floods in residential areas; (d) Mangrove damage in the Passo area and its surroundings

### **Adaptation strategies of coastal communities**

To address the increasing impacts of climate change, coastal communities in Ambon City have implemented various adaptation strategies, categorized into three main approaches: physical, economic, and social adaptation. These strategies are designed to enhance community resilience against rapid and unpredictable environmental changes. The goal is not only to mitigate climate risks but also to improve long-term community well-being.

#### ***Physical adaptation: Infrastructure development and ecosystem rehabilitation***

One of the primary physical adaptation strategies involves infrastructure development to protect coastal areas from erosion and tidal flooding. The construction of seawalls and improved drainage systems have been implemented to mitigate the damage caused by rising sea levels. These infrastructures are essential in reducing the direct impact of extreme weather events and maintaining the stability of coastal settlements (Anjani *et al.*, 2023).

In addition to infrastructure development, ecosystem rehabilitation is also a key focus. Mangrove reforestation efforts aim to strengthen coastal resilience against erosion while enhancing the ecosystem's role as a natural carbon sink. Mangroves help dissipate large waves and provide critical habitats for marine species. Coral reefs are also being protected through coral transplantation programs to restore the balance of marine ecosystems threatened by rising sea temperatures (Berhиту & Kalalimbong, 2009). These initiatives actively involve local communities, ensuring their participation in coastal ecosystem conservation.

***Economic adaptation: Livelihood diversification***

As the fisheries sector become increasingly affected by climate change, coastal communities are adopting livelihood diversification as an economic adaptation measure. Beyond traditional fishing activities, they are exploring eco-tourism, small and medium enterprises (SMEs), and climate-resilient coastal agriculture. Diversification aims to reduce dependence on a single income source and provide more sustainable economic options (Anugraha *et al.*, 2022).

Several programs have been introduced in Ambon City, including skill training in seafood processing, such as smoked fish and fish floss production, as well as the development of conservation-based marine tourism (Ferdinandus & Suryasih, 2014; Tuhuteru, 2023). Mangrove tourism and snorkeling activities around Ambon's coastal waters are emerging as alternative economic opportunities (Desa Waiheru, 2024). This diversification allows communities to be more adaptable to ongoing environmental changes.

***Social adaptation: Institutional strengthening and community participation***

From a social perspective, strengthening community-based institutions is crucial in enhancing socio-ecological resilience. The formation of fisher groups, community cooperatives, and disaster response teams improves the adaptive capacity of coastal communities. These groups serve as platforms for sharing information, receiving training, and accessing support to cope with climate change. With these institutions, communities are better organized to respond to environmental crises and disasters (Assis *et al.*, 2023). Additionally, empowering women in coastal communities is an integral part of social adaptation strategies. In many cases, women play a vital role in household economic resilience, particularly through micro-enterprises such as seafood-based product manufacturing. Increasing their involvement in community decision-making ensures a more inclusive and sustainable adaptation approach.

***Education and outreach: Enhancing community awareness and capacity***

Improving public understanding of climate change and adaptation strategies is a crucial component of resilience-building efforts. Educational and outreach programs have been implemented in various coastal communities to provide information on climate change impacts, disaster mitigation, and environmentally friendly practices. Through

these initiatives, communities can better comprehend weather pattern changes and prepare for potential risks (**Rahmawati *et al.*, 2023**).

Coastal schools have also begun integrating climate change topics into their curriculum. This early education ensures that younger generations develop an awareness of climate change impacts and the importance of environmental conservation. Additionally, local governments collaborate with universities to offer training programs for fishers and coastal farmers, enabling them to adopt more sustainable and eco-friendly practices in their daily activities. These training programs cover various topics, including sustainable fishing techniques, aquaculture best practices, organic farming methods, and the use of climate-resilient crops. Participants are also introduced to coastal resource management strategies to help mitigate environmental degradation.

### **Utilizing technology for climate change adaptation**

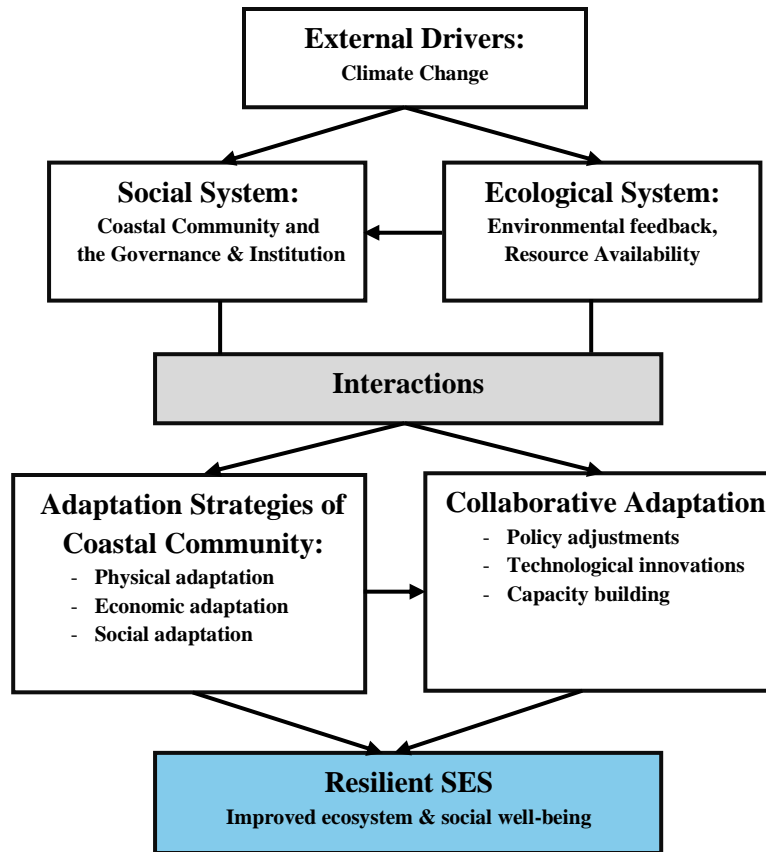
Technology-driven strategies have also been adopted by coastal communities in Ambon City. The implementation of early warning systems for detecting extreme weather events and high waves has assisted fishers in determining safe fishing times. These systems utilize meteorological data to provide accurate and reliable information to coastal communities, thereby reducing the risk of maritime accidents (**Steven *et al.*, 2020**).

Moreover, ecological-based aquaculture technology is increasingly being employed as a solution to maintain food security and economic stability. Sustainable fish and seaweed farming systems enable coastal communities to secure income without relying solely on declining fish stocks due to climate change. These technologies also enhance production efficiency while minimizing environmental impacts (**Hiwasaki *et al.*, 2014**).

### **Collaboration with stakeholders for sustainable adaptation**

Adaptation efforts cannot be effectively implemented without collaboration among communities, governments, and other stakeholders. Local governments play a vital role in establishing regulations that support coastal ecosystem protection, providing incentives for sustainable adaptation practices, and developing policies based on scientific data. Support from the private sector and non-governmental organizations (NGOs) also contributes to funding and technological advancements needed to enhance community adaptation capacity (**Sodikin *et al.*, 2023**).

One example of collaborative adaptation in Ambon City is the partnership between local governments and research institutions to develop community-based adaptation models. This approach ensures that implemented solutions are well-suited to local conditions and community needs. Through synergy among various stakeholders, adaptation strategies can be executed more effectively, generating long-term positive impacts for coastal communities. Generally, the adaptive collaborative strategy between the government and coastal communities in addressing climate change is presented in Fig. (4).



**Fig. 4.** Collaborative adaptation model of coastal communities to climate change

### Mitigation strategies for climate change in Ambon City's urban coastal zone

To effectively manage climate change impacts in Ambon City's urban coastal zone, the local government can implement several mitigation strategies:

1. **Green Open Space Management:** Expanding and maintaining urban green areas, such as parks and coastal buffer zones, can help absorb CO<sub>2</sub>, regulate temperature, and reduce flood risks (Rahman *et al.*, 2020b).
2. **Mangrove Conservation and Restoration:** Protecting existing mangrove forests and restoring degraded areas will prevent coastal erosion (Sunkur *et al.*, 2023), enhance carbon sequestration (Rahman *et al.*, 2024a), and support marine biodiversity (Rahman *et al.*, 2024b).
3. **Sustainable Urban Planning:** Implementing climate-resilient urban planning strategies, such as restricting development in vulnerable coastal areas and integrating eco-friendly infrastructure, will help minimize environmental degradation.
4. **Waste Management and Pollution Control:** Reducing plastic waste and controlling industrial pollution will mitigate the impacts of climate change by maintaining healthy coastal ecosystems.

5. **Community-Based Coastal Adaptation Programs:** Engaging local communities in climate adaptation initiatives, such as eco-tourism, sustainable fisheries, and mangrove stewardship programs, will enhance resilience.
6. **Early Warning Systems and Disaster Preparedness:** Strengthening climate monitoring and disaster preparedness measures will help anticipate extreme weather events and protect coastal communities.

These strategies, when implemented collectively, can significantly contribute to mitigating climate change impacts and ensuring sustainable development in Ambon City.

## CONCLUSION

In conclusion, coastal communities in Ambon City face various climate change impacts, including coastal erosion, tidal flooding, declining fish catches, and coastal ecosystem degradation. This study identifies that community adaptation strategies fall into three main approaches: physical, economic, and social adaptation.

Physical adaptation includes the construction of sea walls, improved drainage systems, and ecosystem rehabilitation efforts such as mangrove reforestation and coral reef conservation programs. In the economic aspect, livelihood diversification plays a crucial role, with communities shifting towards ecotourism, small and medium enterprises, and climate-resilient coastal agriculture to reduce dependence on fisheries, which are increasingly affected by climate change. Meanwhile, social adaptation is carried out through the strengthening of community institutions, the formation of fisher groups and cooperatives, as well as education and outreach programs on climate change and disaster mitigation.

This study also highlights the importance of integrating technology into adaptation strategies, such as the implementation of early warning systems for extreme weather and the use of ecological-based aquaculture technology. Collaboration among communities, governments, and various stakeholders is identified as a key factor in developing sustainable adaptation solutions.

By adopting a more holistic and community-based approach, this study recommends that climate change adaptation policies consider socio-ecological aspects comprehensively, ensuring that coastal communities in Ambon City can enhance their resilience against the ongoing environmental changes.

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