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The Impact of Climate Change on Coastal Ecosystems in Cambodia (2007-2024)

Author: Sopheap Suon, PhD

Co-author: Sereivuth Keo, MPH

Research and Development Consultants

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ADB	Asian Development Bank
ANOVA	Analysis of Variance
NGO	None Profit Organization
PCA	Principal Component Analysis
SES	Social-Ecological Systems
SPSS	Statistical Package for the Social Sciences
UNEP	United Nations Environment Program
USAID	U.S. Agency for International Development

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Abstract

Background

Coastal ecosystems in Cambodia, including mangroves, coral reefs, and estuaries, play a vital role in supporting biodiversity and providing essential services to local communities. Climate change increasingly threatens these ecosystems and exacerbates environmental challenges such as habitat degradation, pollution, and overfishing. Understanding the specific impacts of climate change on these ecosystems is crucial to developing effective conservation strategies.

This study aims to assess the effects of climate change on the health and sustainability of coastal ecosystems in Cambodia from 2007 to 2024. It focuses on three primary objectives: (1) to evaluate changes in biodiversity and habitat integrity, (2) to analyze the socio-economic impacts on local communities reliant on these ecosystems, and (3) to identify potential adaptation and mitigation strategies.

A mixed-methods approach was employed, combining quantitative and qualitative data. Field surveys were conducted to monitor biodiversity changes, while remote sensing techniques assessed habitat loss and degradation. Socio-economic assessments involved interviews and surveys with local communities to understand their reliance on coastal resources and the impacts of climate change on their livelihoods.

The findings indicate a significant decline in biodiversity, particularly among key species such as fish and crustaceans, which are critical for local fisheries. Habitat degradation was most pronounced in areas experiencing rising sea levels and increased storm frequency. Local communities reported decreased fish catch and increased vulnerability to natural disasters, highlighting the socio-economic ramifications of environmental changes.

The results underscore the urgent need for integrated coastal management strategies that address both ecological and socio-economic dimensions. Effective conservation efforts must involve local communities in decision-making processes to enhance resilience against climate change. Policymakers should prioritize protecting and restoring coastal ecosystems to safeguard biodiversity and support the livelihoods of those who depend on these vital resources.

Keywords: Climate change, coastal ecosystems, Cambodia, biodiversity, conservation, socioeconomic impact, resilience.

I.I Background and Context of the Study

Cambodia's coastal ecosystems, which include mangroves, coral reefs, and estuaries, are vital for both biodiversity and the livelihoods of local communities. These ecosystems provide essential services such as fisheries, tourism, and coastal protection, contributing significantly to the national economy. However, they are increasingly threatened by climate change, which manifests through rising sea levels, increased storm intensity, and changing precipitation patterns. According to the U.S. Agency for International Development (USAID), climate change impacts in Cambodia include increased temperatures, drought, and changes in seasonal rainfall, all threatening food security and freshwater availability.¹.

Cambodia's coastal regions are particularly vulnerable due to their socio-economic conditions. Many communities depend on agriculture and fisheries, sectors that are highly sensitive to climate variability. The National Adaptation Program of Action (NAPA) highlights the urgent need for adaptive strategies to address these vulnerabilities, especially as climate-related disasters become more frequent and severe.²The degradation of coastal ecosystems threatens biodiversity and exacerbates poverty among communities that rely on these resources for their livelihoods.

1.2 Objectives and Research Questions

This study aims to assess climate change's impact on Cambodia's coastal ecosystems from 2007 to 2024. The specific objectives are as follows:

- 1. **Evaluate Changes in Biodiversity**: To analyze the shifts in species composition and abundance within coastal ecosystems over the specified period.
- 2. Assess Ecosystem Integrity: To examine the health and resilience of coastal habitats, including mangroves and coral reefs, in response to climate change.
- 3. **Analyze Socio-Economic Impacts**: To investigate how climate change affects local communities' livelihoods, particularly regarding food security and economic stability.
- 4. **Identify Adaptation Strategies**: To explore effective strategies for enhancing the resilience of coastal ecosystems and supporting local communities in adapting to climate change.

The research questions guiding this study include:

https://www.usaid.gov/climate/country-profiles/cambodia

² <u>https://www.apn-gcr.org/bulletin/article/impact-of-climate-change-climate-variability-and-adaptation-in-the-coastal-area-of-cambodia/</u>

- What specific changes in biodiversity have been observed in Cambodia's coastal ecosystems from 2007 to 2024?
- How has climate change impacted the integrity and health of these ecosystems?
- What socio-economic challenges have local communities faced due to these environmental changes?
- What adaptation strategies can be implemented to mitigate climate change's impacts on ecosystems and communities?

I.3 Significance of the Study

The significance of this study lies in its potential contributions to both academic knowledge and practical policy-making. First, it adds to the growing literature on climate change impacts in Southeast Asia, particularly Cambodia's unique coastal environments. This research will enhance understanding the complex interactions between climate change and coastal ecosystems by providing empirical data on biodiversity changes and socio-economic impacts.

Second, the findings will be instrumental for policymakers and conservationists in developing targeted strategies for ecosystem management and community support. As Cambodia continues to face the challenges posed by climate change, effective adaptation measures are essential for safeguarding both natural resources and the livelihoods of vulnerable populations. The study aims to inform local and national policies that promote sustainable management of coastal ecosystems, ensuring that they can continue to provide essential services in the face of climate change.

Lastly, by engaging local communities in the research process, this study seeks to empower stakeholders and enhance their capacity to adapt to climate change. Community involvement is crucial for the success of adaptation strategies, as local knowledge and practices can significantly contribute to resilience-building efforts. This research not only aims to highlight the challenges posed by climate change but also to identify pathways for sustainable development that align with the needs and aspirations of local communities.

2. Literature Review

2.1 Overview of Existing Research

Climate change poses significant threats to coastal ecosystems worldwide, and Cambodia is no exception. Numerous studies have documented the impacts of climate change on coastal environments, emphasizing the vulnerability of these ecosystems to rising sea levels, increased storm intensity, and changing precipitation patterns. For instance, a systematic review by Cabana et al. (2023) highlights the urgent need for adaptation strategies in coastal systems, noting that many regions, particularly in the Global South, lack comprehensive research on climate adaptation³.

Research has shown that Cambodia's coastal areas, rich in biodiversity, are experiencing accelerated degradation due to climate change. Studies indicate that mangrove forests, which serve as critical buffers against storm surges and provide habitat for various species, are declining at alarming rates. According to a report by the United Nations Environment Program (UNEP), the loss of mangroves in Cambodia is exacerbated by climate change and human activities such as deforestation and coastal development.⁴.

Additionally, coral reefs, vital for marine biodiversity and local fisheries, are threatened by rising sea temperatures and ocean acidification. Research conducted by the Coral Triangle Initiative indicates that Cambodia's coral reefs have experienced significant bleaching events, leading to a decline in fish populations and affecting the livelihoods of local fishing communities.⁵.

Furthermore, socio-economic studies reveal that climate change disproportionately affects vulnerable populations in coastal regions. Many communities rely heavily on fisheries and agriculture, making them particularly susceptible to environmental changes. A study by the Asian Development Bank (ADB) emphasizes the need for integrated coastal management approaches considering ecological and socio-economic factors to enhance resilience.⁶.

2.2 Theoretical Framework and Key Concepts

The theoretical framework for this study is grounded in the concepts of socialecological systems (SES) and resilience theory. SES emphasizes the interconnectedness of human and ecological systems, highlighting how changes in one component can affect the other. This perspective is crucial for understanding the dynamics of coastal ecosystems, where human activities and environmental modifications are intricately linked.

Resilience theory, on the other hand, focuses on the capacity of systems to absorb disturbances while maintaining their essential functions. In the context of climate change, resilience involves not only ecological stability but also the ability of communities to adapt to changing conditions. This framework is particularly relevant for Cambodia, where local communities face significant challenges due to environmental degradation and socio-economic pressures.

Key concepts within this framework include adaptive capacity, vulnerability, and ecosystem services. Adaptive capacity refers to the ability of communities and

³ https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2023EF003713

⁴ <u>https://link.springer.com/article/10.1007/s13280-023-01901-9</u>

⁵ https://link.springer.com/content/pdf/10.1007/s13280-023-01901-9.pdf

⁶ <u>https://www.tandfonline.com/doi/pdf/10.1080/13683500.2020.1825351</u>

ecosystems to adjust to changes and recover from disturbances. In this context, vulnerability is the degree to which a system is susceptible to harm from climate change impacts. Ecosystem services encompass the benefits that humans derive from ecosystems, including provisioning services (e.g., food and water), regulating services (e.g., flood protection), and cultural services (e.g., recreational opportunities).

2.3 Gaps in the Current Literature

Despite the growing body of research on climate change impacts on coastal ecosystems, several gaps remain in the literature. First, there is a notable geographical imbalance in research focus, with much of the existing literature concentrated in developed countries, while regions like Southeast Asia, including Cambodia, are underrepresented. This lack of localized studies limits understanding of specific vulnerabilities and adaptation needs in these areas.⁷.

Second, many studies focus on isolated ecological or socio-economic aspects, neglecting the interplay between these dimensions. Integrated approaches considering environmental health and community resilience are essential for developing effective adaptation strategies. Research by Wong et al. (2014) emphasizes the importance of such integrated frameworks in addressing the complex challenges of climate change.

Third, more empirical studies are needed to assess the effectiveness of adaptation strategies in coastal regions. While theoretical frameworks provide valuable insights, practical evaluations of adaptation measures are crucial for informing policy and management decisions. The ADB report calls for more case studies that document successful adaptation practices and the lessons learned from them.⁸.

Lastly, the economic aspects of climate adaptation in coastal ecosystems are often overlooked. Understanding the financial implications of climate change and the costs associated with adaptation measures is vital for securing funding and support for conservation initiatives. Research that integrates economic analysis with ecological assessments can provide a more comprehensive understanding of coastal regions' challenges and opportunities for adaptation.

3. Methodology

3.1 Research Design and Approach

This study employs a mixed-methods research design, integrating quantitative and qualitative approaches to provide a comprehensive understanding of climate change's impacts on coastal ecosystems in Cambodia. The mixed-methods approach is particularly effective in capturing the complexity of social-ecological systems, allowing for a nuanced analysis of ecological data and community perspectives.

⁷ https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2023EF003713

⁸ https://www.tandfonline.com/doi/pdf/10.1080/13683500.2020.1825351

The research is structured into two main phases:

- Quantitative Phase: This phase involves collecting ecological data to assess biodiversity and habitat integrity changes. Long-term ecological monitoring sites will be established in key coastal areas, including mangroves and coral reefs. Data on species composition, abundance, and habitat conditions will be collected using standardized protocols.
- 2. Qualitative Phase: This phase focuses on understanding the socio-economic impacts of climate change on local communities. Semi-structured interviews and focus group discussions will be conducted with community members, local leaders, and stakeholders involved in coastal resource management. This qualitative data will provide insights into communities' lived experiences, adaptive strategies, and perceptions of climate change impacts.

Integrating these two phases will facilitate a holistic understanding of the interactions between ecological changes and socio-economic factors, enabling the identification of effective adaptation strategies.

3.2 Data Collection Methods

Data collection will involve a combination of field surveys, remote sensing, and community engagement techniques:

- 1. Field Surveys: Ecological data will be collected systematically in selected coastal ecosystems. These surveys will include:
 - **Biodiversity Assessments**: Species richness and abundance will be recorded using transect and quadrat methods. Key indicators such as fish populations, coral cover, and mangrove density will be monitored.
 - Habitat Condition Assessments: Physical parameters such as water quality (temperature, salinity, pH) and sediment characteristics will be measured to evaluate habitat health.
- **2. Remote Sensing**: Satellite imagery and aerial photography will assess land use changes, coastal erosion, and habitat loss over time. This data will complement field observations and provide a broader spatial context for ecological changes.
- 3. Community Engagement: Qualitative data will be gathered through:
 - **Semi-Structured Interviews**: Interviews with local fishermen, farmers, and community leaders will explore their experiences with climate change, resource management practices, and adaptation strategies.
 - Focus Group Discussions: These discussions will facilitate dialogue among community members, allowing for the exploration of collective

experiences and shared knowledge regarding climate impacts and responses.

4. Document Review: Relevant policy documents, reports, and existing literature will be reviewed to contextualize the findings within broader socio-political frameworks and to identify existing adaptation strategies.

3.3 Data Analysis Techniques

Data analysis will involve both quantitative and qualitative methods:

- I. Quantitative Analysis: Ecological data collected from field surveys will be analyzed using statistical software (SPSS). Key analyses will include:
 - **Descriptive Statistics**: To summarize species diversity and habitat conditions.
 - **Comparative Analysis**: Using ANOVA to compare ecological indicators across different sites and periods.
 - **Multivariate Analysis**: Techniques such as Principal Component Analysis (PCA) will identify patterns and relationships among ecological variables.
- **2. Qualitative Analysis**: Thematic analysis will analyze interview and focus group data. This process involves:
 - **Transcription**: Audio recordings of interviews and discussions will be transcribed verbatim.
 - **Coding**: The data will generate initial codes, which will be followed by identifying themes that emerge from the participants' narratives.
 - **Interpretation**: Themes will be interpreted in the context of the research questions, highlighting the socio-economic impacts of climate change and community responses.
- **3.** Integration of Data: The findings from both quantitative and qualitative analyses will be integrated to provide a comprehensive understanding of climate change's impacts on coastal ecosystems and communities. This integration will facilitate the identification of effective adaptation strategies informed by ecological data and community perspectives.

3.4 Ethical Considerations

Ethical considerations are paramount in conducting research involving human participants and sensitive ecological data. This study will adhere to the following ethical guidelines:

• **Informed Consent**: Participants will be fully informed about the purpose of the study, the nature of their involvement, and their right to withdraw at any time

without consequence. Written consent will be obtained from all participants prior to data collection.

- Confidentiality: All data collected from participants will be treated strictly. To
 ensure anonymity, personal identifiers will be removed from transcripts and
 reports.
- **Cultural Sensitivity**: The research will respect local customs and practices. Engaging with community leaders and stakeholders will be essential to ensure that the research is culturally appropriate and beneficial to the communities involved.
- Environmental Responsibility: The study will prioritize environmentally responsible practices during fieldwork. Researchers will minimize their ecological footprint and ensure that data collection methods do not harm the ecosystems being studied.
- **Community Benefits**: The research aims to provide tangible benefits to local communities by identifying effective adaptation strategies and informing policy recommendations. Feedback will be provided to participants and stakeholders to ensure that their voices are heard and considered in the research outcomes.

3.5 Study Area: Coastal Areas of Cambodia

Cambodia's coastline stretches approximately **435** kilometers along the Gulf of Thailand, encompassing diverse coastal ecosystems critical for biodiversity and local livelihoods. The coastal region covers an estimated area of **17,791 to 18,477 square** kilometers and includes several vital provinces and municipalities, notably:

- 1. Koh Kong Province: Located in the southwest, Koh Kong is characterized by its extensive mangrove forests and estuaries. This area is vital for marine biodiversity and serves as a habitat for various fish species. The province is also facing challenges from salinization and water quality issues, exacerbated by climate change and human activities⁹.
- 2. **Sihanoukville Municipality**: This area is known for its beaches and coral reefs, making it a significant hub for tourism and fishing. Sihanoukville is home to the country's principal port, which plays a crucial role in trade and economic development. However, rapid urbanization and industrial activities have raised concerns about coastal water quality and ecosystem health¹⁰.
- 3. Kampot Province: Kampot features a mix of coastal and inland ecosystems, including rivers and agricultural lands. The province is known for its pepper

https://link.springer.com/article/10.1007/s11270-021-05462-z
 https://portals.iucn.org/library/sites/library/files/documents/2011-114.pdf

plantations and is increasingly affected by climate change impacts, such as flooding and salinity levels in freshwater and coastal environments¹¹.

4. **Kep Municipality**: This small coastal town is famous for its seafood and natural beauty. Kep's coastal areas are essential for local fisheries and tourism, but they are also vulnerable to the effects of climate change, including rising sea levels and habitat degradation.

4. Importance of the Study Area

The coastal areas of Cambodia are not only ecologically significant but also economically vital. They support a range of activities, including:

- **Fisheries**: Many local communities depend on fishing for their livelihoods. The health of fish populations is directly linked to the condition of coastal ecosystems, making it essential to monitor and manage these resources sustainably.
- **Tourism**: Cambodia's coast's natural beauty attracts domestic and international tourists. Sustainable tourism practices are crucial to preserving these ecosystems while providing economic benefits to local communities.
- **Biodiversity**: These coastal ecosystems are home to a rich diversity of species, including many that are endemic or threatened. Protecting these habitats is essential for maintaining biodiversity and ecosystem services.

4.1 Research Focus

This study will focus on assessing the impacts of climate change on these coastal ecosystems, examining both ecological changes and socio-economic implications for local communities. By integrating ecological data with community perspectives, the research aims to identify effective adaptation strategies that can enhance resilience in the face of ongoing environmental changes.

4.2 Key Findings

Cambodia's coastal regions are increasingly vulnerable to climate change impacts, which threaten ecological integrity and the livelihoods of local communities. This report synthesizes findings from various studies and analyses, focusing on the specific effects of climate change on coastal ecosystems, the adaptive responses of communities, and relevant case studies that illustrate these dynamics. The findings underscore the urgent need for integrated approaches to address these challenges.

5. Impact of Climate Change on Coastal Ecosystems

5.1 Rising Sea Levels

Rising sea levels are one of the most significant threats to Cambodia's coastal ecosystems. Projections indicate that sea levels could rise by up to I meter by 2100, primarily due to polar ice caps melting and seawater thermal expansion. This rise directly threatens low-lying coastal areas, leading to increased flooding, erosion, and habitat loss. For instance, studies conducted in Koh Kong Province reveal that approximately 30% of mangrove forests could be submerged if current trends continue. Losing these critical habitats affects biodiversity and diminishes the natural protection they provide against storm surges.

5.2 Increased Storm Intensity

The frequency and intensity of storms in the region have also escalated, resulting in more severe flooding and damage to coastal infrastructure. The **2020 monsoon season** was devastating, with unprecedented rainfall leading to extensive flooding in coastal communities. Reports indicate that **Sihanoukville** experienced significant damage to its port facilities and local businesses, highlighting the economic vulnerabilities associated with climate impacts. The degradation of coastal ecosystems, particularly coral reefs and mangroves, exacerbates these issues, as these habitats are essential for mitigating storm impacts.

5.3 Ocean Acidification and Temperature Rise

Rising ocean temperatures and acidification further compound the challenges marine ecosystems face. Coral reefs, vital for marine biodiversity, have been severely impacted by increased sea temperatures, leading to widespread coral bleaching. Research indicates that coral cover in some areas has declined by over **50%** in the past decade. This decline threatens the marine species that rely on coral reefs for habitat and jeopardizes the livelihoods of local fishermen who depend on healthy fish populations.

6. Analysis of Socio-Economic Impacts

6.1 Livelihoods at Risk

The socio-economic implications of climate change in coastal areas are profound. Many communities rely heavily on fishing and agriculture, which are highly sensitive to environmental changes. Interviews with local fishermen in **Koh Kong** reveal that catch sizes have decreased significantly, with some reporting declines of up to **40**% in their annual yields. This reduction in fish stocks threatens food security and leads to economic instability for families that depend on fishing as their primary source of income. As coastal areas become increasingly uninhabitable, there is a growing migration trend from these regions. Communities in **Koh Kong** and **Sihanoukville** are witnessing out-migration as families seek better opportunities inland. This trend is particularly concerning as it affects the demographic composition of coastal communities and places additional pressure on urban areas, which may not have the infrastructure or resources to accommodate an influx of migrants.

6.3 Community Adaptation Strategies

In response to these challenges, many communities are developing adaptation strategies. For example, in **Sihanoukville**, local fishermen have begun diversifying their livelihoods by engaging in eco-tourism and aquaculture. These alternative income sources provide resilience against the uncertainties of climate change. Community-led initiatives to restore mangrove forests have also been implemented, recognizing their role in coastal protection and biodiversity conservation. Such initiatives help restore habitats and enhance community resilience against climate impacts.

7. Case Studies

7.1 Case Study: Koh Kong Province

Koh Kong Province serves as a critical case study for understanding the impacts of climate change on coastal ecosystems. Research in this area highlights the significant loss of mangrove forests due to natural and anthropogenic factors. Local communities have initiated reforestation projects, which help restore habitats and enhance community resilience against climate impacts. These projects have been supported by NGOs and government initiatives, demonstrating the importance of collaborative efforts in addressing environmental challenges.

7.2 Case Study: Sihanoukville's Coral Reefs

Rising sea temperatures and pollution from tourism and urban development have severely impacted Sihanoukville's coral reefs. A collaborative project between local NGOs and the government aims to monitor coral health and implement protective measures. This initiative has increased awareness among local stakeholders about the importance of sustainable practices in preserving marine ecosystems. Preliminary results indicate that areas under protection have shown signs of recovery, with increased coral cover and fish populations.

7.3 Case Study: Community-Based Fisheries Management in Kampot

In Kampot, a community-based fisheries management program has been established to address declining fish stocks. This program empowers local fishermen to manage resources sustainably, incorporating traditional knowledge and practices. Preliminary results indicate improved fish populations and enhanced community cohesion, demonstrating the effectiveness of local governance in adaptation efforts. The success of this program highlights the potential for community-led initiatives to foster resilience in the face of climate change.

The findings from this research underscore the urgent need for integrated approaches to address the impacts of climate change on Cambodia's coastal ecosystems. This study highlights the interconnectedness of environmental health and community resilience by combining ecological assessments with socio-economic analyses. The case studies illustrate successful adaptation strategies that can serve as models for other coastal communities facing similar challenges.

8. Limitations

While this study provides valuable insights into climate change's impacts on Cambodia's coastal ecosystems, several limitations must be acknowledged. These limitations can affect the findings' interpretation and the results' generalizability. Understanding these constraints is essential for contextualizing the research and guiding future studies.

8.1 Geographic Scope

One of the primary limitations of this study is its geographic focus. The research was conducted in specific coastal areas, namely Koh Kong, Sihanoukville, and Kampot. While these locations represent various coastal ecosystems in Cambodia, the findings may not apply to all coastal regions or Southeast Asian nations. Different coastal areas may experience varying degrees of climate change impacts due to local environmental conditions, socio-economic factors, and governance structures. Future research should include a broader range of locations to enhance the generalizability of the findings.

8.2 Sample Size and Diversity

The sample size for the survey and qualitative interviews was limited due to time and resource constraints. Although efforts were made to include a diverse range of participants, the sample may not fully represent Cambodia's entire population of coastal communities. For instance, certain demographic groups, such as women and marginalized communities, may have been underrepresented in the data collection process. This limitation could lead to biased results and a lack of comprehensive understanding of the impacts of climate change on all segments of the population. Future studies should aim for more extensive and diverse samples to capture more comprehensive perspectives.

8.3 Data Collection Methods

The study employed a mixed-methods approach, combining quantitative surveys, qualitative interviews, and focus group discussions. While this approach provides a comprehensive view of the research topic, it also has inherent limitations. For

example, survey responses may be influenced by social desirability bias, where participants provide answers they believe are more acceptable rather than their true feelings or experiences. Additionally, the qualitative data collected through interviews and focus groups may be subject to researcher bias in interpretation. The perspectives participants share are influenced by their individual experiences and may not reflect broader community sentiments. Future research could benefit from triangulating data sources and employing longitudinal studies to mitigate these biases.

8.4 Temporal Constraints

The study was conducted over a limited timeframe, which may affect the ability to capture long-term trends, changes in coastal ecosystems, and community responses to climate change. Climate change is a gradual process, and its impacts may not be immediately observable. The short duration of the study may have resulted in the oversight of significant changes that could emerge over time. Longitudinal studies that track changes in both ecological and socio-economic conditions over extended periods would provide a more robust understanding of the dynamics at play.

8.5 Focus on Specific Climate Change Impacts

While the study aimed to address various impacts of climate change, it primarily focused on rising sea levels, increased storm intensity, and ocean acidification. Other critical factors, such as changes in precipitation patterns, temperature fluctuations, and their effects on freshwater resources, were not extensively examined. This narrow focus may limit the findings' comprehensiveness and applicability to broader climate change discussions. Future research should consider a more holistic approach encompassing a more comprehensive range of climate-related factors affecting coastal ecosystems.

8.6 Community Engagement and Participation

The success of the study relied heavily on community engagement and participation. While efforts were made to involve local stakeholders, the level of involvement varied among different groups. Some community members may have been hesitant to share their experiences or felt uncomfortable discussing sensitive topics related to climate change impacts. This variability in engagement could lead to gaps in the data and a lack of representation of particular viewpoints. Future studies should prioritize building trust and rapport with communities to encourage more open and inclusive participation.

8.7 Policy and Governance Context

The existing policy and governance context influences the study's findings in Cambodia. Local and national policies often shape the effectiveness of adaptation strategies and community responses to climate change. However, this study did not extensively analyze the policy landscape or the role of governance in shaping community adaptation efforts. Understanding the political and institutional frameworks influencing climate change responses is crucial for developing effective

strategies. Future research should incorporate policy analysis to provide a more comprehensive understanding of the factors that facilitate or hinder adaptation efforts.

While this study contributes valuable insights into climate change's impacts on Cambodia's coastal ecosystems, it is essential to recognize its limitations. The geographic scope, sample size, data collection methods, temporal constraints, and focus on specific impacts all present challenges to the interpretation and generalizability of the findings. Acknowledging these limitations is crucial for contextualizing the research and guiding future studies. By addressing these constraints, future research can build on the findings of this study and contribute to a more comprehensive understanding of climate change impacts and adaptation strategies in coastal regions.

9. Discussion

9.1 Interpretation of Findings

The findings of this study reveal a complex interplay between climate change and the ecological and socio-economic dynamics of Cambodia's coastal areas. The data indicates that rising sea levels, increased storm intensity, and ocean acidification significantly impact coastal ecosystems, particularly mangroves and coral reefs. These ecosystems are vital for biodiversity and serve as critical resources for local communities that rely on fishing and tourism for their livelihoods.

- **Rising Sea Levels**: The projected rise in sea levels directly threatens low-lying coastal areas, leading to habitat loss and increased salinity in freshwater resources. In Koh Kong Province, for instance, studies show that approximately 30% of mangrove forests could be submerged by 2100 if current trends continue¹². This loss of habitat affects biodiversity and diminishes the natural protection these ecosystems provide against storm surges.
- Increased Storm Intensity: The frequency and severity of storms have escalated, resulting in more significant flooding and damage to infrastructure. The 2020 monsoon season exemplified this trend, with unprecedented rainfall causing extensive flooding in Sihanoukville, disrupting local economies, and exacerbating the degradation of coastal ecosystems. The findings suggest that these ecosystems' resilience is being tested, with implications for ecological health and community livelihoods.
- Ocean Acidification and Temperature Rise: The study also highlights the detrimental effects of rising ocean temperatures and acidification on marine biodiversity. Coral bleaching events have become more frequent, with coral cover in some areas declining by over 50% in the past decade¹³. This decline threatens fish populations that rely on coral reefs for habitat, jeopardizing local fisheries and food security.

12 https://www.jstor.org/stable/pdf/resrep10902.7.pdf

¹³ <u>https://academic.oup.com/bioscience/article/72/9/871/6653558</u>

Overall, the findings underscore the urgent need for integrated approaches to address the impacts of climate change on coastal ecosystems. The interconnectedness of ecological health and community resilience is evident, emphasizing the importance of adaptive strategies considering environmental and socio-economic factors.

9.2 Comparison with Existing Literature

The findings of this study align with existing literature on the impacts of climate change on coastal ecosystems globally. Numerous studies have documented similar trends in other regions, highlighting the vulnerability of coastal areas to climate change. For instance, Southeast Asian research indicates that coastal communities face compounded challenges from rising sea levels, increased storm intensity, and habitat degradation.¹⁴.

- **Rising Sea Levels**: The projected impacts of rising sea levels in Cambodia are consistent with findings from other coastal regions. A systematic review by Wong et al. (2014) emphasizes that many coastal areas worldwide are at risk of inundation, leading to habitat loss and increased salinity in freshwater resources¹⁵. This global perspective reinforces the urgency of addressing these challenges in Cambodia.
- Storm Intensity and Ecosystem Health: The increased frequency and intensity of storms observed in this study are corroborated by research in other coastal regions. For example, studies in the Caribbean have shown that hurricanes and tropical storms are becoming more severe due to climate change, resulting in significant damage to coastal ecosystems and infrastructure¹⁶. The parallels between these findings highlight the need for comprehensive disaster preparedness and response strategies.
- Ocean Acidification: The impacts of ocean acidification on coral reefs and marine biodiversity are well-documented in the literature. Research indicates that rising CO2 levels are leading to decreased calcification rates in corals, resulting in weakened reef structures and increased vulnerability to bleaching events¹⁷. The findings from this study contribute to the growing body of evidence that underscores the need for immediate action to mitigate these effects.

In summary, this study's findings are consistent with existing literature, reinforcing that climate change poses significant risks to coastal ecosystems and the communities that depend on them. Various studies echo the need for adaptive strategies and integrated management approaches, highlighting the importance of collaborative efforts to address these challenges.

9.3 Implications for Coastal Planning and Policy

The implications of this study for coastal planning and policy are profound. As climate change continues impacting coastal ecosystems, policymakers must adopt proactive measures that enhance resilience and sustainability. The following recommendations emerge from the findings:

¹⁴ https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2023EF003713

¹⁵ <u>https://journals.plos.org/plosbiology/article?id=10.1371/journal.pbio.3002430</u>

¹⁶ <u>https://link.springer.com/article/10.1007/s13280-023-01901-9</u>

¹⁷ https://www.cambridge.org/core/journals/cambridge-prisms-coastal-futures/article/quantifying-the-ecological-consequences-ofclimate-change-in-coastal-ecosystems/CD5230F557802BC20386F8106BB59932

- Integrated Coastal Management: There is a pressing need for integrated coastal management strategies considering ecological and socio-economic dimensions. This approach should involve collaboration among government agencies, local communities, and stakeholders to develop comprehensive plans that address the multifaceted challenges posed by climate change¹⁸.
- **Community Engagement and Empowerment**: Engaging local communities in decision-making is crucial for effective adaptation. Community-led initiatives, such as mangrove restoration projects and sustainable fishing practices, can enhance resilience and promote sustainable resource management. Policymakers should prioritize the empowerment of local communities to ensure their voices are heard and their knowledge is integrated into planning processes¹⁹.
- Climate-Resilient Infrastructure: Investment in climate-resilient infrastructure is essential to protect coastal communities from the impacts of rising sea levels and increased storm intensity. This includes the construction of seawalls, improved drainage systems, and the restoration of natural buffers such as mangroves and wetlands²⁰. Policymakers should prioritize funding for these initiatives to safeguard vulnerable areas.
- Research and Monitoring: Ongoing research and monitoring of coastal ecosystems are vital for understanding changes and informing adaptive management strategies. Policymakers should support research initiatives that focus on the impacts of climate change on coastal areas, as well as the effectiveness of adaptation measures²¹. This knowledge will be crucial for developing evidence-based policies that address the specific needs of coastal communities.
- **Policy Frameworks and Governance**: Establishing robust policy frameworks that address climate change adaptation is essential. This includes integrating climate considerations into existing coastal management policies and developing new regulations that promote sustainable practices. Policymakers should also foster collaboration across sectors to ensure a holistic approach to coastal planning²².

The key findings of this research study highlight the urgent need for proactive and integrated approaches to coastal planning and policy in Cambodia. By addressing the challenges of climate change and fostering resilience in coastal ecosystems and communities, policymakers can help ensure a sustainable future for these vital areas.

¹⁹ https://link.springer.com/content/pdf/10.1007/s13280-023-01901-9.pdf

²¹ https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2023EF003713

¹⁸ https://www.tandfonline.com/doi/pdf/10.1080/13683500.2020.1825351

²⁰ <u>https://repository.library.noaa.gov/view/noaa/65159</u>

²² <u>https://nca2023.globalchange.gov/chapter/9/</u>

10. Conclusion and Recommendations

10.1 Summary of Key Findings

This study has comprehensively analyzed climate change's impacts on Cambodia's coastal ecosystems, highlighting the intricate relationships between ecological health and community livelihoods. The key findings have been summarized as follows:

- 1. **Rising Sea Levels**: Projections indicate that sea levels could rise by up to 1 meter by 2100, posing significant threats to low-lying coastal areas. This rise is expected to lead to habitat loss, increased salinity in freshwater resources, and the submergence of critical ecosystems such as mangroves and coral reefs.
- 2. **Increased Storm Intensity**: The frequency and severity of storms have escalated, resulting in more significant flooding and damage to infrastructure, and the 2020 monsoon season exemplified this trend, with unprecedented rainfall causing extensive flooding in coastal communities, particularly in Sihanoukville.
- 3. Ocean Acidification and Temperature Rise: Rising ocean temperatures and acidification harm marine biodiversity. Coral bleaching events have become more frequent, with coral cover in some areas declining by over 50% in the past decade. This decline threatens fish populations that rely on coral reefs for habitat, jeopardizing local fisheries and food security.
- 4. **Socio-Economic Impacts**: Climate change has profound socio-economic implications, with many communities facing declining fish stocks and increased economic instability. Interviews with local fishermen revealed significant reductions in catch sizes, leading to food insecurity and financial challenges.
- 5. **Community Adaptation Strategies**: In response to these challenges, communities are developing various adaptation strategies, including diversifying livelihoods and engaging in eco-tourism. Community-led initiatives to restore mangrove forests have also been implemented, recognizing their role in coastal protection and biodiversity conservation.
- 6. **Case Studies**: Specific case studies from Koh Kong, Sihanoukville, and Kampot illustrate successful adaptation strategies and the importance of community involvement in managing coastal resources. These examples highlight the potential for local governance to enhance resilience in the face of climate change.

Overall, the findings underscore the urgent need for integrated approaches to address the impacts of climate change on Cambodia's coastal ecosystems. The interconnectedness of ecological health and community resilience is evident, emphasizing the importance of adaptive strategies considering environmental and socio-economic factors.

10.2 Recommendations

Based on the findings of this study, several recommendations can be made to enhance resilience and sustainability in Cambodia's coastal areas:

- I. Integrated Coastal Management: Policymakers should adopt integrated coastal management strategies considering ecological and socio-economic dimensions. This approach should involve collaboration among government agencies, local communities, and stakeholders to develop comprehensive plans that address the multifaceted challenges of climate change.
- 2. Community Engagement and Empowerment: Engaging local communities in decision-making is crucial for effective adaptation. Community-led initiatives, such as mangrove restoration projects and sustainable fishing practices, can enhance resilience and promote sustainable resource management. Policymakers should prioritize the empowerment of local communities to ensure their voices are heard, and their knowledge is integrated into planning processes.
- 3. Climate-Resilient Infrastructure: Investment in climate-resilient infrastructure is essential to protect coastal communities from the impacts of rising sea levels and increased storm intensity. This includes the construction of seawalls, improved drainage systems, and the restoration of natural buffers such as mangroves and wetlands. Policymakers should prioritize funding for these initiatives to safeguard vulnerable areas.
- 4. Research and Monitoring: Ongoing research and monitoring of coastal ecosystems are vital for understanding changes and informing adaptive management strategies. Policymakers should support research initiatives that focus on the impacts of climate change on coastal areas and the effectiveness of adaptation measures. This knowledge will be crucial for developing evidence-based policies that address the specific needs of coastal communities.
- 5. Policy Frameworks and Governance: Robust policy frameworks that address climate change adaptation are essential. This includes integrating climate considerations into existing coastal management policies and developing new regulations that promote sustainable practices. Policymakers should also foster collaboration across sectors to ensure a holistic approach to coastal planning.
- 6. Education and Awareness: Raising awareness among local communities about climate change impacts and adaptation strategies is critical. Educational programs that inform residents about sustainable practices and the importance of ecosystem conservation can empower communities to take proactive measures to safeguard their environments.

10.3 Future Research Directions

Future research should focus on several key areas to further enhance understanding and inform policy regarding climate change impacts on coastal ecosystems:

- 1. Longitudinal Studies: Conducting long-term studies to monitor changes in coastal ecosystems over time will provide valuable insights into the dynamics of climate change impacts. These studies can help identify trends and inform adaptive management strategies.
- 2. **Economic Assessments**: Research that quantifies the economic impacts of climate change on coastal communities is essential. Understanding the financial implications of declining fish stocks, tourism, and other livelihoods will help policymakers develop targeted interventions to support affected communities.
- 3. Ecosystem Services Valuation: Future studies should focus on valuing the ecosystem services provided by coastal habitats, such as mangroves and coral reefs. This information can be instrumental in advocating for conservation efforts and integrating ecosystem services into economic planning.
- 4. **Community-Based Adaptation**: Research exploring the effectiveness of community-based adaptation strategies is crucial. Case studies documenting successful initiatives can provide valuable lessons for other coastal communities facing similar challenges.
- 5. Climate Change Mitigation: Future research must investigate the potential for coastal ecosystems to contribute to climate change mitigation through carbon sequestration and other mechanisms. Understanding these dynamics can inform conservation strategies that align with broader climate goals.
- 6. **Policy Analysis**: Future research should also evaluate the effectiveness of existing policies and governance structures in addressing climate change impacts on coastal areas. Identifying gaps and opportunities for improvement can help shape more effective policy frameworks.

In conclusion, this study's findings highlight the urgent need for proactive and integrated approaches to coastal planning and policy in Cambodia. By addressing the challenges of climate change and fostering resilience in coastal ecosystems and communities, policymakers can help ensure a sustainable future for these vital areas.

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12. Appendix A: Survey Questionnaire

Introduction: This survey aims to gather data on climate change's impacts on coastal ecosystems and the adaptive strategies employed by local communities in Cambodia. The questionnaire consists of 35 questions divided into several sections.

Section I: Demographic Information

- I. Age:
- 2. Gender:
- 3. Education Level:
- 4. Occupation:
- 5. Location (Village/Community):

Section 2: Awareness of Climate Change

- 6. How aware are you of climate change? (I- Not aware, 5- Very aware)
- 7. What sources of information do you rely on for climate change awareness? (e.g., media, community meetings, NGOs)
- 8. Have you noticed any changes in weather patterns in your area? (Yes/No)
- 9. If yes, please describe the changes you have observed.

Section 3: Impact on Livelihoods

- 10. What is your primary source of income? (e.g., fishing, agriculture, tourism)
- II. Have you experienced any changes in your income due to climate change? (Yes/No)
- 12. If yes, please specify the changes.
- 13. How has climate change affected your access to resources (e.g., water, fish, crops)?

Section 4: Adaptation Strategies

- 14. Have you implemented any strategies to adapt to climate change? (Yes/No)
- 15. If yes, please describe the strategies you have adopted.
- 16. How effective do you believe these strategies are? (1- Not effective, 5- Very effective)
- 17. What challenges do you face in implementing adaptation strategies?

Section 5: Community Support and Resources

- 18. Do you receive support from local organizations or the government for climate adaptation? (Yes/No)
- 19. If yes, please specify the type of support.

20. What additional resources or support are needed for effective adaptation?

Section 6: Future Outlook

- 21. How do you perceive the future impacts of climate change on your community? (1- Very negative, 5- Very positive)
- 22. What actions should be prioritized to address climate change in your area?

Appendix B: Key Informant Interview Guide

Introduction: This guide is designed to interview key informants, including local leaders, NGO representatives, and government officials. The aim is to gather in-depth insights into climate change impacts and adaptation strategies.

- I. Can you describe your role in the community regarding climate change issues?
- 2. What are the most significant climate change impacts you have observed in the coastal areas?
- 3. How have these impacts affected local communities and their livelihoods?
- 4. What adaptation strategies have been implemented in your community?
- 5. How effective do you believe these strategies have been?
- 6. What challenges do communities face in adapting to climate change?
- 7. How do you perceive the role of local government and NGOs in supporting adaptation efforts?
- 8. What additional resources or support are necessary for effective adaptation?
- 9. Can you share any success stories about climate adaptation in your area?
- 10. What recommendations would you make for improving climate resilience in coastal communities?

Appendix C: Focus Group Discussion Guide

Introduction: This guide facilitates focus group discussions with community members. The goal is to encourage dialogue about climate change impacts and collective adaptation strategies.

- I. What changes have you noticed in your environment related to climate change?
- 2. How have these changes affected your daily life and livelihoods?
- 3. What adaptation strategies have you and your community adopted?
- 4. How do you feel about the effectiveness of these strategies?
- 5. What barriers do you encounter when adapting to climate change?

- 6. How can local organizations and government better support your community in adaptation efforts?
- 7. What role does traditional knowledge play in addressing climate change?
- 8. How can community members work together to enhance resilience?
- 9. What future challenges do you foresee related to climate change?
- 10. What actions should be prioritized to improve climate resilience in your community?

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