Coastal Zone Health Index (CoZHI) for Sustainable Development and Management

持続可能な開発と管理に資するための沿岸域健康指数（CoZHI）

Thesis

Submitted in partial fulfillment of the requirements of the degree of

Doctor of Philosophy

by

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Thesis Approval

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Declaration

I hereby declare that I have completed the present work, entitled "**Coastal Zone Health Index (CoZHI) for Sustainable Development and Management**", without illegal aid from outside sources. There are no further source aids besides those listed, which have indicated sections borrowed verbatim from the utilized references. Furthermore, this dissertation incorporates material that has previously been published by the author in a peer-reviewed journal but is an important part of this manuscript and dissertation. The data, certain parts of the methodology, chapter 4, and chapter 7.1.1 are derived from the published work. The integration of this material is intended to provide a cohesive presentation of my research findings.

Jonathan **CABRERA**

Hiroshima, May 22, 2024

Certificate of Coursework

This is to certify that **CABRERA JONATHAN SALAR** was admitted to the candidacy of a Ph.D. degree after completing all the courses required for the Ph.D. program. The details of the coursework are given below.

No	Course Name	Credits
1	Regional development seminar from the viewpoint of the SDGs	1
2	Data Science	2
3	Academic Writing II	1
4	Technology Strategy and R&D Management	1
5	Basic Preparing Future Faculty Course	2
6	Hiroshima Peace Studies I	2
7	Remote Sensing for Social Sciences	2
8	Idea Mining Workshop	1
9	Data Visualization A	1
10	Data Visualization B	1
11	Artificial and Natural Intelligence	2
12	Computational Science	2
13	Numerical Environmental Impact Assessment 1	2
14	Numerical Environmental Impact Assessment 2	2
15	Data Analytics for Sustainable Development	2
16	Agent-based Transport Simulation	2
17	Long-term Internship	2
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Abstract

In the face of increasing coastal zone degradation caused by anthropogenic activities and climate change, there is an urgent need for innovative models that encompass the health and sustainability of coastal ecosystems. This study introduces the coastal zone health index (CoZHI). It is an innovative multidisciplinary framework for assessing, monitoring, and guiding the sustainable development and management of coastal zones. This study, which is based on a comprehensive methodological approach that incorporates the analytical hierarchy process (AHP) under multicriteria decision analysis (MCDA), explores the complex interactions among human activities, coastal ecosystem services, and climate-related impacts. This study focused on ten diverse criteria for coastal zone health assessment. These include tourism, biodiversity, carbon storage, coastal livelihoods, protection, natural products, clean water, fisheries, marine culture, and sense of place. Furthermore, this study employs diverse datasets and indicators for vulnerability assessment, including shoreline change, geomorphology, elevation, sea surface temperature, sea level rise, and significant wave height. It also includes socioeconomic variables to determine the impact of changing coastal zone phenomena.

This paper demonstrates significant differences in coastal zone health across city contexts, emphasizing the importance of local governance, community engagement, and policy integration in fostering resilience and sustainability. The adaptability of the CoZHI framework to local decision-makers' perspectives highlights the importance of the data and decision-driven strategies to coastal zone management. This study showcases the dynamic tensions and potential combined effects between environmental conservation and socioeconomic development objectives by comparing conservationist, non-extractive, extractive, and strongly extractive development views. Furthermore, this research adds to the ongoing conversation about integrated coastal zone management (ICZM) by offering practical solutions to reduce susceptibility to hazards and enhances the coastal zone communities resiliency in the changing climate.

Finally, this study introduces a flexible and scalable framework for evaluating coastal zone health and promotes a more sustainable coastal management practice. The CoZHI framework stands out as a vital tool for policymakers and researchers in offering a thorough approach in protecting the coastal zone environment while considering the socioeconomic

needs of coastal communities. Thus, this dissertation enhances our understanding of coastal zone environmental health dynamics and drives towards sustainable coastal development.

Keywords: Coastal Zone Health Index (CoZHI), Coastal Zone Resource, Coastal Zone Vulnerability, Analytical Hierarchy Process (AHP), MCDA-based Decision Science

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Chapter 1 - Introduction

1.1. General Background

The coastal zone connects terrestrial and marine environments. It is the planet's most productive ecosystem. Major cities are in coastal areas. It is estimated that 23% of the world's population lives within 100 km of coastal areas (Small & Nicholls, 2003). The attractiveness of the coastal landscape and seascape encouraged the rapid expansion of human settlements and increased economic activity in the area. The rapid expansion of urban cities to coastal zones have been attributed to the degradation of coastal zone ecosystems (Petrişor et al., 2020). The major human activities affecting the coastal zone include massive sewage discharge (Sumaila & Tai, 2020), coastal water pollution (Bajt et al., 2019; Cochard, 2017), overfishing (Sumaila & Tai, 2020), deforestation (Taylor et al., 2022; Ury et al., 2021), reclamation (Li & Zhang, 2021), sand and oil mining (Jordaan, 2012), tourism (Miller & Hadley, 2005), trade, energy production (Tuy et al., 2022a, 2022b); and construction of seawalls and other structures (Salauddin et al., 2021). Furthermore, engineering projects such as waterway and coastal structures change circulation patterns and alter natural methods of sediment transport (Pörtner et al., 2022). As a result, human activities frequently interfere with coastal zone ecosystem services. In addition to human activities, the coastal zone environment is also impacted by water-related phenomena caused by climate changes, such as typhoons (Wang et al., 2016), storm surges (Lee, 2013; Lee et al., 2013; Mcinnes et al., 2003), tsunamis caused by underwater tectonic and volcanic earthquakes (Nistor & Saatcioglu, 2012), sea level rise (Mcinnes et al., 2003), and rapid increase of sea surface temperature (Fingas, 2019). Human activities and water-related phenomena typically have negative impacts on economic activities, resulting in social issues such as unemployment, development loss, and resource competition among stakeholders.

Thus, an inclusive framework for understanding the interaction between human impacts and climate change in coastal zone ecosystems should be developed. An integrated and comprehensive coastal resource management framework is critical for balancing human coexistence in coastal zones. Furthermore, the framework should ensure that natural disasters do not have a significant impact on coastal ecosystems. The framework ensures the fair use of coastal and marine resources. The framework ensures the fair utilization of coastal and marine resources. The framework should align socioeconomic development with the existence of coastal zone ecosystems to ensure the integrity of coastal zone environments. Furthermore, the plan's development should be coordinated with the local community, policymakers, and academic institutions committed to societal sustainability.

Integrated coastal zone management (ICZM) is recognized as one of the most effective tools for incorporating conservation and sustainable use of marine and coastal biodiversity aspects into the planning of coastal areas (Pickaver et al., 2004). This framework is a dynamic, multidisciplinary, iterative process for promoting sustainable coastal zone management. A long-term evaluation is needed to balance socioeconomic activities within the constraints imposed by the natural dynamics of the coastal zone environment. It also incorporates all relevant policy areas, sectors, and levels of government (e.i., local, regional, and national) (Olsen, 2003; Pickaver et al., 2004). The primary goal of ICZM initiatives is to preserve, restore, or improve specific characteristics of coastal ecosystems and their human communities (Fingas, 2019).

The Marine Environment and Resources Foundation in the Philippines studied the Coastal Integrity Vulnerability Assessment Tool (CIVAT) and developed a framework for assessing the vulnerability of coastal zones to physical processes such as coastal erosion and flooding (Siringan et al., 2013). The potential impact of these physical processes is determined by their exposure to coastal dynamics, such as wave action, as well as their biophysical sensitivity, such as erosion susceptibility. This CIVAT framework attempts to assess the adaptive capacity of coastal zone areas to physical processes and water-related phenomena. This tool can also be used to calculate how human activities and development impact coastal areas. These findings provide useful information about the potential effects of climate change on the vulnerability of coastal areas, with sea level rise and other impacts likely to cause significant changes (Siringan et al., 2013).

Halpern et al. (2012) proposed an ocean health index (OHI) framework for assessing ocean health based on multiple goals. The objectives are as follows: food provision (subgoals: fisheries and mariculture), artisanal fishing opportunities, natural products, carbon storage, coastal protection, tourism and recreation, coastal livelihoods and economies, sense of place, clean waters, and biodiversity (subgoals: habitats and species). This framework focuses on understanding the health of the marine environment, including coastal activities.

Every framework described above has a unique technique and limitations. The OHI framework's limitation is that each goal is given equal weight when evaluating the environment's health. The paper on OHI needed to capture the decision-makers perspective in the study area. The coastal zone health index (CoZHI) framework used in this study addressed the limitations of the OHI framework. The CoZHI framework includes perspectives from policymakers as well as the local community. The OHI and CoZHI frameworks have similar approaches for understanding the integrity of the coastal zone environment from the past to the present. CIVAT, on the other hand, expands the capabilities of the OHI and ICM frameworks by considering the future effects of climate change on coastal areas.

The proposed CoZHI framework is multidisciplinary and measures ten indicators (or ten public goals in the OHI framework). The difference between the CoZHI and the OHI is the ability of the CoZHI framework to adapt to decision-makers' perceptions. The CoZHI framework also utilizes vulnerability assessment criteria from the CIVAT assessment tool. Furthermore, the variables in the CIVAT are limited only to sea level rise (SLR) and wave exposure. The CoZHI includes the SLR, wave, geomorphology, shoreline change, elevation, and sea surface temperature. Furthermore, the CoZHI includes socioeconomic variables such as population, age, marital status, household size, literacy, and difficulties (seeing, hearing, walking, self-care) from the recent Philippine Statistics Authority census. It also includes pre- and post-exposure to the coastal zone due to extreme events such as typhoons, tsunamis, and storm surges. Moreover, CoZHI is a multidisciplinary and iterative process that involves assessing the health and integrity of the coastal zone environment, similar to the ICZM framework. Unlike the ICZM, the CoZHI will assess the current health and integrity of the coastal zone environment.

Thus, this study focuses on developing an adaptive framework for assessing the coastal zone health index. The framework is flexible to policymakers' perceptions, providing input to coastal zone management plans. Here, 'adaptive' refers to the flexibility of the framework in terms of the weights of each criterion, which can be adjusted based on the perceptions of decision-makers in a specific city. This adaptability allows the framework to incorporate local insights and preferences, ensuring that management strategies are tailored to the unique conditions and priorities of each coastal area. The weights of the indicators can be identified via the analytical hierarchy process (AHP) under multicriteria decision analysis (MCDA). This study aims to establish an expert-driven CoZHI framework and to provide integrated policies on human settlements focused on coastal zone resources.

1.2. Literature Review

Coasts, seas, and oceans are part of the coastal zone environment, and they are considered areas of significant importance from ecological, social, economic, and cultural perspectives (Sierra-Correa et al., 2024). The distinctive dynamics of the coastal zone environment translate into abundant biodiversity and provide environmental and socioeconomic services. The coastal zone environment represents the most exploited environment throughout the world. Coastal zones constitute 4% and 11% of the earth's total land area and the world's oceans, respectively (Sierra-Correa et al., 2024). Yet, it contains one-third of the world's population (Cabrera & Lee, 2022) and provides 90% of the marine fisheries (Barbier, 2017).

These environments are threatened by increasing population, habitat reforestation and degradation, overexploitation, pollution, climate change, and other factors (Barbier, 2017). Hence, there is a need to strengthen policies and management to make use of sustainable use while ensuring the present and future provision of coastal zone services (De Fontaubert, Downes, & Agardy, 1996; Egoh et al., 2007). In light of these challenges, it is imperative to adopt a more holistic approach to coastal zone management. This involves not only addressing immediate threats but also anticipating future challenges. For instance, the impact of climate change on coastal zones is likely to intensify in the coming years, necessitating proactive measures to mitigate its effects. Thus, several approaches in the ICZM have been applied at global, regional, national, and local scales to address the complexity and dynamics of the coastal zone environment (Bocci et al., 2024; De Fontaubert, Downes & Agardy, 1996; Egoh et al., 2007; Irmadhiany et al., 2024; Zhang et al., 2024). It is also worth noting that the effectiveness of these approaches largely depends on the level of cooperation and coordination among various stakeholders. These include government agencies, local communities, nongovernmental organizations, and the private sector. Therefore, fostering a culture of collaboration and shared responsibility is crucial for the successful implementation of ICZM strategies.

In this chapter, we will examine the international and national laws and regulations and regional and national research that contributed to the development and evolution of the ICZM.

Moreover, we will delve into the role of research advancements in enhancing our understanding of coastal zone dynamics and informing policy decisions.

1.2.1. International and Institutional Legal Framework

The origins of the ICZM date to the 1970s when nations began asserting maritime rights, with the United Nations Convention on the Law of the Sea (UNCLOS), which introduced concepts of the Exclusive Economic Zone (EEZ), Territorial Sea, and Continental Shelf (Cicin-Sain & Knecht, 2013; Clark, 1997, 2018; Sorensen & McCreary, 1990). ICZM was recognized as a unique approach to planning at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro (Barua et al., 2020). Since then, numerous studies and publications have underscored the importance of managing coastal zone areas in an integrated way, considering the interactions between sea and land and their significance for ecosystem services and environmental and human-induced pressures (Cicin-Sain & Knecht, 2013; Kay & Alder, 2017).

The ICZM approach has continued to feature in various frameworks, such as the Sustainable Development Goals (like Goal 12 (Bitoun et al., 2024), Goal 13 (Bitoun et al., 2024), and Goal 14 (Arfan et al., 2024)), Biodiversity Framework (Bell-James et al., 2024), the United Nations Ocean Decade Initiatives (Ryabinin et al., 2019), multiple strategies addressing climate change like Blue Carbon (Bertram et al., 2021), and, recently the Ocean Health Index (Halpern et al., 2012). These frameworks highlight the need for a comprehensive and integrated approach to coastal zone management that takes into account the complex interplay between ecological, social, and economic factors.

International, regional, national, local, and community scale policies increasingly emphasize actions to enhance coastal, marine, and marine ecosystem health. The European Union, for instance, developed a Marine Strategy Framework Directive (MSFD) to achieve good environmental status for the EU's marine waters (i.e., coasts, seas, and ocean) and sustainably protect the resource base upon which marine-related economic and social activities depend, and it is a binding principle or directive to encourage Member States to manage the EU’s entire marine environment (European Commission, 2008). MSFD requires member states to develop national marine strategies to achieve, or maintain where it exists, 'good environmental status'. The marine strategies involve routinary marine environment evaluation and monitoring to improve the state of marine waters. The evaluation also include spatial protection measures, as representative network of marine protected areas. The MSFD sets qualitative descriptors to use when determining good environmental status. These descriptors cover a wide range of aspects, from biodiversity maintenance and the reduction of nonindigenous species to the reduction of contaminants and marine litter.

In the United States of America, the National Ocean Policy (NOP) was established by Executive Order 13547 on July 19, 2010, by President Obama. The National Ocean Policy states that federal agencies will "ensure the protection, maintenance, and restoration of the health of ocean, coastal, and Great Lakes ecosystems and resources, enhance the sustainability of ocean and coastal economies, preserve our maritime heritage, support sustainable uses and access, provide for adaptive management to enhance our understanding of and capacity to respond to climate change and ocean acidification, and coordinate with our national security and foreign policy interests" (United States National Ocean Council, 2013). The U.S. NOP aims to (1) protect and restore the health and biological diversity of ocean, coastal, and Great Lakes ecosystems and resources; (2) improve the resiliency of these ecosystems; (3) and strengthen the conservation and sustainable uses of land.

Each nation, including the USA and European countries, employs specific actions, frameworks, and indicators to safeguard their coastal environments. The use of quantitative indicators is crucial in all these efforts, as they are the primary tools for assessing ecosystem health improvements and verifying whether management objectives are being achieved. However, there is no standardized framework to guarantee coastal zone health universally. This study introduces ten diverse indicators designed to monitor the health of the coastal zone environment effectively, highlighting the need for a more unified and standardized approach to coastal zone health assessment.

1.2.2. Philippine legal framework for coastal resource management

The management of coastal resources in the Philippines is underpinned by a comprehensive legal and institutional framework, primarily governed by the 1991 Local Government Code. This framework delineates responsibilities across various levels of governance, from national to local, ensuring a coordinated approach in managing the country's vast coastal and marine environments. At the national level, the Department of Environment and Natural Resources (DENR) and the Department of Agriculture's Bureau of Fisheries and Aquatic Resources (DA-BFAR) are essential, with DENR focusing on coastline development and mangrove management and DA-BFAR overseeing fisheries. Additional support comes from various other agencies, such as the Department of Social Welfare and Development and the Department of Justice, highlighting the multifaceted nature of coastal resource management (CRM).

The national guidelines for ICM are set within the broader context of the Philippine Strategy for Sustainable Development, which aligns with the UN Convention on the Law of the Sea. This strategic approach promotes the integration of environmental considerations in decision-making processes and emphasizes the sustainable use of resources through policies that encourage equitable access, the rehabilitation of damaged ecosystems, and strong pollution controls.

Notably, the DENR's Coastal Environment Program and the National Integrated Coastal Management Training Program enhance public participation and build local capacities for effective CRM. These efforts are complemented at the local level by devolved responsibilities to local government units (LGUs), empowering them to directly manage and influence the conservation and utilization of coastal and marine resources in their respective areas.

Coastal resource management in the Philippines is a multilayered approach involving both national and local institutions under a well-defined legal and institutional framework provided by the Local Government Code and other national policies. The integration of environmental sustainability into policy-making, alongside active participation from local government units and community stakeholders, ensures a comprehensive and inclusive management strategy. These efforts are crucial for the sustainable development and conservation of the Philippines' rich marine and coastal ecosystems, which effectively address both ecological and socioeconomic needs. However, enhancing coordination, improving resource allocation, increasing community engagement, and addressing the nonuniformity of criteria used by different local government units to monitor and manage coastal resources are necessary to overcome the practical limitations of the existing management framework.

1.2.3. Multifaceted Coastal Zone Management

In recent decades, concerns have increased to the impact of human activities on marine and coastal ecosystems, leading to several initiatives seeking to incorporate the concepts of sustainability into policy (Arfan et al., 2024; Bell-James et al., 2024; Bertram et al., 2021;

European Commission, 2008; Ryabinin et al., 2019; United States National Ocean Council, 2013). The Blue Economy is the predecessor of the Green Economy. The Green Economy addresses land resources and neglects the importance of coastal areas and oceans in the economic and cultural lives of people living in coastal zones (Bax et al., 2021). On the other hand, the Blue Economy comprises the economic sectors and related policies to determine the sustainable of marine and oceanic resources (Bax et al., 2022). It is important to understand several characteristics of oceanic sustainability, ranging from sustainable resource utilization to ecosystem health status.

Ocean health is one factor that is highly emphasized in coastal zone resource management (Claudet et al., 2020). The ocean is critical for achieving sustainable development. Thus, SDGs may not be realized without accomplishing Goal 14, which is "Life below water", and this speaks about the health of marine ecosystems. SDG 14 is required to meet other SDGs, such as SDG 1: no poverty, SDG 2: zero hunger, SDG 3: good health, SDG 10: reduced inequalities, and SDG 12: responsible consumption. However, humans increasingly affect marine resources and ecosystems through their use for food, energy production, tourism, and transportation. Moreover, land-based human activities such as waste discharge, coastal urban expansion, and carbon emissions. Such negative human activities alter the ocean's biochemical circulation and properties and alter the habitat species distribution and food webs. There is an urgent need to change human behavior for sustainable development, yet it is also essential to deepen our understanding of environmental challenges to create more effective solutions (Laffoley et al., 2020; Visbeck, 2018).

The United Nations launched the Decade of Ocean Science for Sustainable Development (2021–2030) to address the critical state of the ocean. It aims to foster collaboration among scientists, policymakers, business sectors, nongovernmental organizations, and civil society. This initiative seeks to move beyond traditional approaches and drive significant change. It focuses on addressing the scientific challenges essential for transformative action and achieving sustainable development goals that contribute to a healthier ocean.

Coastal resource management in the Philippines is anchored to legal laws in a comprehensive and integrated coastal management and international framework, as described in subsection 1.2.2. Several recent studies have evaluated marine resources (Christie et al., 2005; Gagarin et al., 2022; Gajardo et al., 2023; Jocson & Magallon Jr, 2018; Madarcos et al., 2021; Muallil et al., 2020; Pollnac & Pomeroy, 2005; Quevedo et al., 2020; Tupper et al., 2015; Walters, 2004).

Unfortunately, every study in the field of coastal management adopts a different approach. The studies of Jocson et al. (2018) are all about coastal vulnerability assessment using the coastal integrated vulnerability assessment tool, and they only address the adverse impact of climate change in the coastal zone environment. Furthermore, the study by Tupper et al. (2015) is limited to evaluating the management of selected marine protected areas in the Philippines. Hence, the studies of Gagarin et al. (2022) focused on people's willingness to pay for mangrove coastal protection, while those of Quevedo et al. (2020) and Madarcos et al. (2021) focused on the perceptions of the local communities on mangrove forest services and the implications of mangroves for disasters and blue carbon management. Hence, success stories of mangrove management were conducted (Walters, 2004). Research on coral reef fishes was conducted by Muallil et al. (2020) and is also a component in the management of coastal resource management.

Coastal resource management studies also include understanding the coastal community. This community is heavily dependent on the sea, marines, and coastal ecosystem services. Thus, researchers have also investigated the sociocultural (Gajardo et al., 2023), quality of life (Pollnac & Pomeroy, 2005), and economic well-being of the community (Ban et al., 2009; Oracion et al., 2005; Samonte-Tan et al., 2007).

Moreover, several studies have focused on the after-effects of the sustainability of ICM projects (Christie et al., 2005; Pollnac & Pomeroy, 2005). These include a multidisciplinary research project on the equitable social and environmental benefits of sustainable ICM (Christie et al., 2005), factors influencing the sustainability of ICM projects in the Philippines (Christie et al., 2005; Pollnac & Pomeroy, 2005), and an evaluation of the effective management of marine protected areas in the Philippines (Tupper et al., 2015).

As we observed, the United Nations developed an integrated coastal resource management framework to determine the health of the coast, seas, and ocean. Every country develops laws, regulations, and frameworks anchored to the UNCLOS. The United States of America has the guidelines of National Ocean Policy, while the European Union has the Marine Strategy Framework Directive (MSFD) that every state should follow to achieve good environmental status for the EU's marine waters (i.e., coasts, seas, and ocean). The Philippines has several laws to protect and maintain the coastal zone environment. Other countries not mentioned here have laws and frameworks designed to protect their territorial marine ecosystems that are aligned with the UNCLOS.

Generally, the guidelines are in place, yet the conduct of the studies is diverse. In the case of the Philippines, some research is limited only to the perception of the community of coastal resource projects or the evaluation of the sustainability of coastal resource management. Others focused on certain areas, such as mangrove assessment, fisheries, corals, coastal tourism, hazards, and disasters. Thus, Halpern et al. (2012) address this research gap by combining multiple indicators (i.e., 10 diverse goals in their study), and this study is called the Ocean Health Index (OHI) (Halpern, 2020; Halpern et al., 2012). The OHI framework has the following indicators: (1) fisheries and mariculture, (2) artisanal fishing opportunities, (3) natural products, (4) carbon storage, (5) coastal protection, (6) tourism and recreation, (7) coastal livelihoods and economies, (8) sense of place, (9) clean waters, and (10) biodiversity. The OHI framework focuses on understanding the health of coastal and marine environments. Combining ten diverse indicators requires a proper weighting scheme. The OHI gives equal weight to every indicator. This weighting scheme is based on the author's perception without recognizing the perceptions of the decision-makers in a certain community, city, or country. Additionally, all decision-makers or policymakers have their perceptions of how to develop and maintain the sustainability of their environment. Although the OHI framework addresses the limitations of related previous frameworks and studies, it also has limitations. Thus, this paper enhanced the concept of OHI by allowing decision-makers to participate in the development of the weighting scheme. In this paper, an expert-driven coastal zone health index (CoZHI) framework was developed. The CoZHI framework includes perspectives from policymakers as well as the local community. The OHI and CoZHI frameworks have similar approaches for understanding the integrity of the coastal zone environment from the past to the present. The CoZHI framework also includes a coastal vulnerability assessment to determine how the changing climate also affects the integrity of the coastal zone environment.

Thus, this research aims to develop an innovative adaptive framework for evaluating the coastal zone health index (CoZHI). This framework is designed to be highly adaptable, incorporating the perspectives of policymakers to inform and enhance coastal zone management plans. Additionally, this study will determine the relative importance of various indicators that influence coastal zone health using multicriteria decision analysis. The goal of this study is to create an expert-driven CoZHI framework that systematically integrates stakeholder inputs and preferences. Furthermore, this study seeks to propose comprehensive and integrated policy recommendations that address the complexities of human settlements and their interactions with coastal zone resources. These policies will aim to balance development and conservation efforts, ensuring sustainable management of coastal environments.

1.3. Thesis Outline

- Chapter 1 is the introduction of the study and related studies, including the purpose of the study.
- Chapter 2 provides a discussion of the study area and datasets.
- Chapter 3 presents the overall methodological framework.
- Chapter 4 discusses coastal zone resource assessment (CRA).
- Chapter 5 describes the coastal zone vulnerability assessment (CVA).
- Chapter 6 describes the development of the adaptive expert-driven coastal zone health index (CoZHI) framework.
- Chapter 7 shows the integrated CoZHI framework.
- Chapter 8 presents the conclusions of the study and its limitations, including the feasibility of future work.

Chapter 2 - Materials

2.1. Study Area

The Philippines is a Southeast Asian Island nation located in the Pacific Ring of Fire, facing both the Pacific Ocean and the South China Sea. It consists of 7,640 islands grouped into three major geographical divisions. These are Luzon, Visayas, and Mindanao. The Philippines has an area of 300,000 km^2. As of 2020, the Philippines has a total population of 109 million. Philippine is the 12th most populous country in the world. In this study, the identified study areas are the cities of Davao, Mati, Cagayan de Oro, Cebu, Puerto Princesa, Metro Manila, and Laoag, as shown in Figure 1.

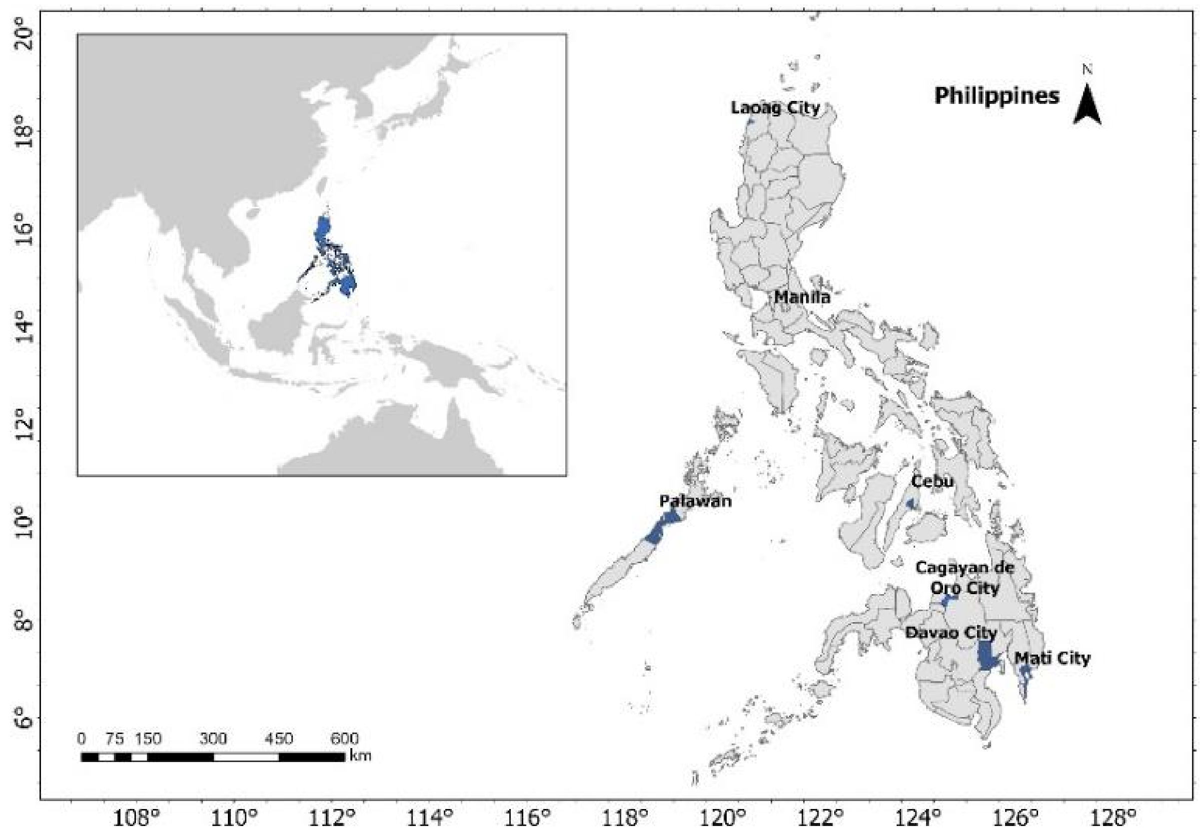

Figure 1. Study areas, the seven major coastal cities in the Philippines.

Davao City is a densely populated city in the southern region of the Philippines, covering 2443.61 km^2. Davao City has the most land area of any city in the Philippines. It is also Mindanao's most populous city, as well as the Philippines's third most populous city. Its population is 1,776,949 (PSA, 2020).

Mati City is a 5th class component city and the capital of Davao Oriental province. It has a population of 147,547 (PSA, 2020). The city is surrounded by the stunning Mt. Hamiguitan Mountain range, a UNESCO Heritage Site. The Department of Environment and Natural Resources (DENR) has designated this city as one of the world's most beautiful bays, with a protected landscape and seascape.

The City of Puerto Princesa is a 1st class, highly urbanized city located in the western Philippine province of Palawan. It is the westernmost city in the Philippines. It has a population of 307,079 people (PSA, 2020). This city is the least densely populated in the Philippines, with 110 inhabitants per km^2. This city has the second-largest geographical area of 2,381.02 km^2. The small islands are the leading tourist destination in this city, with beautiful beach resorts. Also, it is the cleanest and greenest city in the Philippines.

Laoag is the capital city of Ilocos Norte province. It is a 3rd class city. This city is the commercial and industrial hub in the province of Ilocos Norte. Laoag experiences the prevailing monsoon climate and is sometimes experienced by powerful typhoons. The population of Laoag was 111,651 as of the 2020 census (PSA, 2020).

Cebu City is a 1st class, highly urbanized city in the Central Visayas region. It has a population of 964,169 residents as of 2020 (PSA, 2020). This city is the sixth-most populated city in the nation and the most populous in the Visayas. This city is the Philippines' main domestic shipping port, and approximately 80% of the country's domestic shipping companies are located here.

Manila City is the capital of the Philippines. It is the second-most populous city in the country and one of the most populous urban areas in the world. It is highly urbanized and among the most populous and fastest-growing cities in Southeast Asia. The city's total population of 1,846,513 in 2020 (PSA, 2020).

Cagayan de Oro City is a 1st class, highly urbanized city in the northern part of Mindanao. According to the 2020 census, it has a population of 728,402 residents (PSA, 2020). This city also serves as this region's regional center and business hub.

This paper develops an expert-driven CoZHI framework. The assessment of coastal zone vulnerability and the evaluation of the health of coastal cities were conducted only in Davao and Mati city due to the limitations of monetary resources. Fortunately, this study can be continued in future work in other cities by following the same assessment.

2.2. Data

There are two datasets used in this study. First, the coastal zone vulnerability assessment datasets are shown in Table 1. Table 2 shows the datasets used for the coastal zone health assessment. The working description of each indicator in the CoZHI framework is described in the following subsections.

Table 1. Coastal zone vulnerability assessment parameters.

Datasets	Source	Resolution	Period
Significant Wave Height	ERA5	Daily	2013-2023
Elevation	SRTM / Survey	30 m	2023
Sea Level Change Rate	PSMSL	Daily	2013-2023
Geomorphology	Survey	-	2023
Sea Surface Temperature	ERA5	Daily	2013-2023
Shoreline Change Rate	Landsat OLI	30 m	2013 & 2023

Table 2. Coastal zone health assessment criteria.

Datasets	Data source	Resolution/Period
Biodiversity (B)	Landsat (earthexplorer.usgs.gov)	30m / 2013 & 2022
Carbon Storage (CS)	Landsat (earthexplorer.usgs.gov)	30m / 2013 & 2022
Coastal Livelihood (CL)	Philippine Statistics Authority	2000 – 2022
Coastal Protection (CP)	Landsat (earthexplorer.usgs.gov)	30m / 2013 & 2022
Clean Water (CW)	Survey	2022
Fisheries (F)	Bureau of Fisheries and Aquatics Resources	2018 - 2022
Marine Culture (MC)	Bureau of Fisheries and Aquatics Resources	2018 – 2022
Natural Products (NP)	Bureau of Fisheries and Aquatics Resources	2018 – 2022
Sense of Place (SP)	Survey	2024
Tourism and Recreation (TR)	Department of Tourism	2014-2023

2.2.1. Coastal Zone Resource Criteria

2.2.1.1. Biodiversity (B)

Biodiversity refers to the variety and variability of life, encompassing the diversity within species, between species, and within ecosystems (Rondon et al., 2023). This multifaceted concept highlights the critical importance of biodiversity for ecosystem resilience, human well-being, and the provision of ecosystem services essential for life (Tian et al., 2023; Wee et al., 2023).

In the context of this paper, the mangrove ecosystem has been utilized to assess biodiversity. Mangroves are among the most productive and biologically complex ecosystems on Earth and offer a wide range of environmental benefits and services. They play a crucial role in coastal protection and carbon sequestration and serve as nurseries for many marine species. The assessment of biodiversity in mangrove ecosystems focuses not only on species richness and ecosystem functions but also on the existential values these ecosystems offer, particularly concerning their protection status and contribution to marine biodiversity.

Figure 2 depicts the two main stages of determining mangrove spatial distribution. The first stage is data processing. It begins with extracting satellite imagery from the Landsat Operational Land Imager (OLI). This stage determines the spatial location of mangroves using six environmental factors. These are elevation, aspect, hill shade, slope, normalized difference vegetation index (NDVI), and surface reflectance with detailed information provided in Table 3. Furthermore, 100 sample locations in each city were selected to ensure the robustness of the modeling process and facilitate training and testing assessments. Figure 3 depicts this detailed mapping, including the various types of mangrove species.

The second stage involves spatial modeling with the maximum entropy (Maxent) algorithm. Maxent is based on information theory and statistics, and can infer species distributions from presence-only data by maximizing the distribution's entropy (or uncertainty) within known constraints (Saputra & Lee, 2021). This method is especially useful for ecological studies such as those predicting species distributions, such as those involving mangroves. This study used 100 known mangrove presence samples, with training and testing data split 80-20. The Maxent modeling results are expected to reveal potential spatial locations for mangroves and the environmental factors that have the greatest influence on these locations. This method provides a spatial understanding of mangrove distribution, which can support effective efforts to protect and manage coastal biodiversity. The detailed mapping, including the various types of mangrove species, is shown in Figure.

The use of technologies such as satellite imagery and Maxent modeling, as depicted in the framework, offers a comprehensive and systematic approach to assessing mangrove forest biodiversity. This approach not only contributes to our understanding of these vital ecosystems but also aids in their conservation and management.

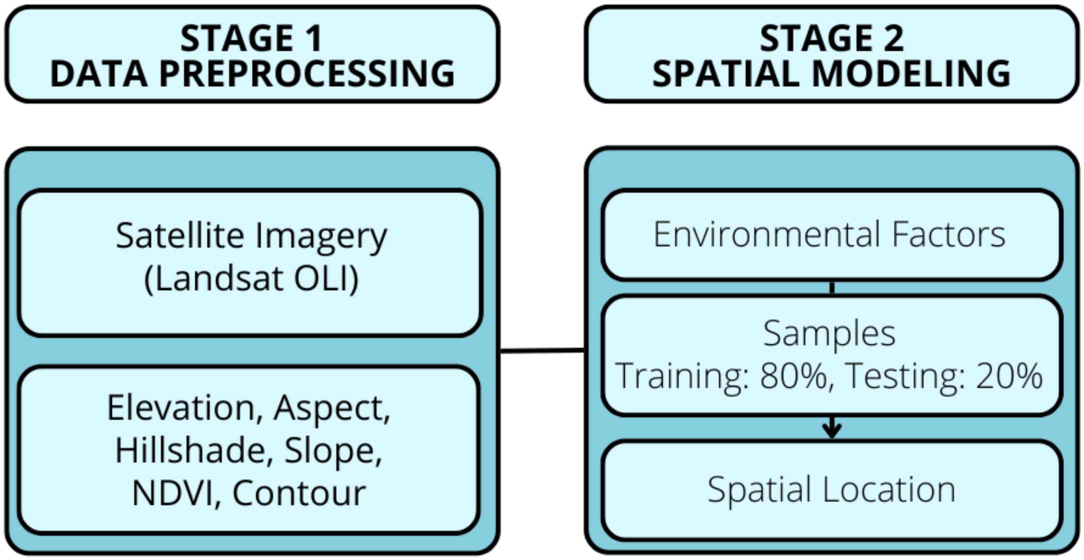

Figure 2. Framework for the mangrove forest assessment.

Table 3. Datasets for the biodiversity, coastal protection, and carbon storage assessment.

Data	Source	Type	Extraction Method
Elevation	Landsat OLI 8	.tif	Spatial Analysis
Aspect	Derived from DEM	.tif	Spatial Analysis
Slope	Derived from DEM	.tif	Spatial Analysis
Temperature	ERA5	.tif	Spatial Analysis
Hillshade	Derived from DEM	.tif	Spatial Analysis
Surface Reflectance	Landsat OLI 8	.tif	NDVI Analysis
Samples	Primary Source	.csv	Survey / Satellite

Figure 3. Types of mangroves and sample points in the mangrove forest.

2.2.1.2. Carbon Storage (CS)

Carbon storage refers to the process of capturing carbon dioxide (CO_2) from the atmosphere or industrial emissions and securing it in a stable form in a reservoir to prevent its release into the atmosphere (Zhang & Huisingh, 2017). This concept encompasses both technological approaches, such as carbon capture and storage (CCS), where CO_2 is captured from power plants or industrial processes, compressed, transported, and stored underground in geological formations, and natural processes, such as the sequestration of carbon in soils through enhanced agricultural practices or the restoration of ecosystems such as forests, peatlands, and mangroves (Dynarski et al., 2020; Ontl & Schulte, 2012).

In this study, the spatial distribution of mangroves was utilized to determine carbon sequestration. The spatial results from Section 2.2.1.1 were used as the data input for the computations of the blue carbon initiative. According to the Blue Carbon Initiative, a hectare of mature mangrove forest can absorb approximately 840 metric tonnes of carbon dioxide (CO_2) over 25 years of average growth. This means that mangroves can absorb 33.6 metric tonnes of CO_2 annually. Additionally, the above-ground portion of mangroves can absorb 39.93 +-14.05 metric tonnes (Ray et al., 2011). In this case, the Blue Carbon Initiative estimation was used. The formula for calculating the annual carbon sequestration of mangroves is annual CO_2 sequestration (metric tonnes/year), which is equal to the area (hectares) multiplied by the CO_2 sequestration rate (metric tonnes/hectares/year).

2.2.1.3. Coastal Livelihood (CL)

The majority of the world's population lives in coastal areas and is highly dependent on marine resources (Ferrol-Schulte et al., 2015). The conditions of marine and coastal ecosystems, which most coastal residents depend on for their livelihoods, are closely related to those livelihoods (Salafsky & Wollenberg, 2000). The fisheries sector provides approximately 179 million jobs worldwide, and the majority are employed at small-scale and artisanal fisheries (Andrew et al., 2007). In addition, the common livelihoods of coastal communities that contribute to the blue economy are mariculture production, fishing, tourism, and coastal aqua forestry (Shalli et al., 2024). Many places around the world, particularly tropical nations, have coastal and marine ecosystems that are showing signs of degradation. This degradation can cause lasting harm and ultimately jeopardize coastal livelihoods (Ferrol-Schulte et al., 2015). In Southeast Asia, more than 90% of coral reefs are at risk of local threats (Tundi et al., 2005). The overexploitation of marine resources has increased over the last 30 years (Department, 2000). The loss of coastal and marine ecosystems hinders the ability of the United Nations SDGs to reduce poverty and hunger. The vulnerability of coastal marine-dependent sectors to the depletion of these resources requires policy intervention. Therefore, coastal livelihoods are an important component of this research study.

This study draws on data from the Philippine Statistics Authority (PSA) Region XI and city-specific offices to examine the scope of coastal livelihoods. According to the PSA survey, jobs in coastal livelihoods are classified as skilled agriculture, forestry, or fishery workers. This paper focused on the number of such workers in each city's coastal barangays (towns).

2.2.1.4. Coastal Protection (CP)

Coastal settlements are becoming increasingly vulnerable to natural disasters such as storm surges, tsunamis, and cyclones. These natural disasters can produce destructive storm surges and waves and are eventually exacerbated by coastal erosion and sea level rise (Marois & Mitsch, 2015). In the past decade, Typhoon Haiyan caused massive destruction in the Philippines, including the nearby Southeast Asian nation, in 2013. This event may have been frequent due to climate change. Thus, effective and sustainable coastal protection is a pressing concern in every nation. Given that mangrove forests are found in many of the locations that are susceptible to cyclones and tsunamis, conserving, restoring, and planting mangrove forests may be one way to find action (Assessment, 2005).

Mangroves are a group of halophytic tree and shrub species commonly found in the coastal areas of regions with tropical and subtropical climates due to their low tolerance to cold temperatures (Marois & Mitsch, 2015). Mangroves can adapt and survive to the salinity, anoxia, and tidal hydrology conditions found in coastal ecosystems. Thus, it may improve the capacity to provide coastal protection from strong waves and soil erosion. It also provides many other valuable ecosystem services, such as biomass, fish sanctuaries, recreation, and carbon sequestration. To some extent, one island near the Leyte Peninsula survived the strong and devastating storm surges caused by Typhoon Haiyan. This is a good example of the use of mangrove forests for coastal protection. Therefore, mangroves need to be considered valuable resources for sustainable management.

Mangroves serve as vital natural barriers, providing significant protection to coastal areas against various environmental threats, such as coastal erosion, tidal waves, tsunamis, and storm surges. The evidence for the capacity of mangrove forests for coastal protection has gained more importance within the last decade because of important international agreements, such as the Sustainable Development Goals and Sendai Framework for Disaster Risk Reduction (Ihinegbu et al., 2023). Mangrove forests stabilize coastlines; reduce erosion from storm surges, currents, waves, and tides; and act as natural barriers that can absorb and dissipate energy from storms and tsunamis, thereby reducing the impact on inland ecosystem areas (Akram et al., 2023; Bimrah et al., 2022; Ihinegbu et al., 2023). In this study, the mangrove spatial distribution was utilized to determine the extent of mangrove protection in coastal zone areas, as described in the spatial results from Section 2.2.1.

2.2.1.5. Water Quality (WQ)

The majority of the world's most productive marine ecosystems are found in coastal areas, and their productivity, diversity, and abundance of life are due to their proximity to land (Bierman et al., 2011). Continental shelf zones are important places for biological activity, generating biological products that sustain 90% of global fish catches (Pauly et al., 2002). Coastal marine areas also have more biodiversity than open ocean zones. These productive marine environments provide crucial habitats for various marine species, which are vital sources of food for humans and also esential components of marine ecosystems (Bierman et al., 2011). The proximity of these ecosystems to land offers a variety of services to the coastal community. However, the threat of rapid and disruptive changes to water quality through anthropogenic and natural phenomena often increases due to the connection to the land. The changes in the water quality can be disastrous for ecosystems, as marine species are endangered by the unsuitability of the environment for survival. Humans are also a factor in changes in water quality because of excessive utilization, such as recreation, fishing, and industry. Maintaining optimal levels of water quality is crucial for the survival and growth of aquatic species and for supporting the livelihoods of communities, particularly small-scale fisheries that depend on these waters. Coastal water quality is affected by both natural phenomena, such as cyclones and floods, and human-induced factors, including pollution from agricultural and industrial discharge and hydrological changes due to development activities. These impacts can lead to challenges such as food insecurity, loss of biodiversity, and occupational displacement for those reliant on marine resources (Nair & Nayak, 2023). Human dependence on these marine resources entails proper regulatory interventions, and reliable ecosystem condition indicators are needed for decision-making (Bierman et al., 2011; Gupta et al., 2003). Thus, it is essential to monitor the health and quality of water in the environment. Traditional monitoring methods include the assessment of biological measurements of water quality, which are based on in situ data collection and hence are often spatially or temporally limited (Vaiciute et al., 2012). Advancements in water quality monitoring and assessment techniques, such as the use of satellite imagery for tracking algal blooms and dissolved oxygen levels, have become increasingly important for understanding and mitigating the impacts of both natural and anthropogenic factors on coastal water quality (Bergamasco et al., 2021).

In this study, we conducted an in situ survey to test the water quality in two cities. Then, we determined if it was within the allowable threshold as described in the DENR Department Order 34 (DENR DAO 34). The acceptable DO concentration is 7.0–8.0 mg/L. The TDS is < 39 mg/L, the salinity is between 33 and 38 ppt, and the acceptable pH is 6.5-8.5.

2.2.1.6. Fisheries (F)

Global overfishing is a pressing international issue that endangers marine populations, ecosystem stability, and food availability for human consumption (Potts et al., 2016). The United Nations' SDG 14 (Life Below Water) aims to safeguard marine ecosystems, regulate fishing practices, halt overfishing, and promote sustainable economic utilization of marine resources. Although there are encouraging indications that the condition of many commercially fished populations is improving (Hilborn et al., 2020), management reform still needs to catch up in many parts of the world, and even in areas with robust governance mechanisms, certain fisheries still need to be reported.

Fisheries encompass the practices of capturing aquatic wildlife, ranging from artisanal to industrial scales, for food, economic activities, and livelihood sustainability. This sector is integral to food security, providing essential nutrition through seafood and supporting millions of jobs worldwide. The sustainable management of fisheries is crucial for ensuring the long-term viability of these resources, addressing overfishing, habitat destruction, and the impacts of climate change on marine biodiversity (Nair & Nayak, 2023). The importance of fisheries extends beyond economic contributions ensuring the resilience and functionality of marine environments. The challenge of managing fisheries sustainably has become more severe, necessitating advancements in monitoring, regulatory frameworks, and community-based management practices to mitigate the impacts of overfishing and environmental degradation. Thus, it is vital to include fisheries as a criterion to determine the health of the coastal zone environment.

In this study, the data for this analysis were sourced from annual reports by the Bureau of Fisheries and Aquatic Resources (BFAR) Region XI and local government offices in Mati city and Davao City.

2.2.1.7. Marine Culture (MC)

Mariculture refers to the cultivation of marine organisms in their natural or controlled marine environments. It has emerged as a significant sector within aquaculture, offering a sustainable alternative to traditional capture fisheries. A steady supply of seafood plays a crucial role in sustaining food security. Economically, mariculture enhances the livelihoods of coastal communities through job creation and the generation of revenue from the export of marine products. Moreover, mariculture is pivotal for advancing research and innovation, leading to the development of more efficient and eco-friendly aquaculture technologies. The key literature that delves into the intricacies of mariculture includes works by Lovatelli et al. (2013), who explore the challenges and opportunities of expanding mariculture offshore in their FAO technical workshop proceedings. Additionally, Shumway's (2011) examination of aquaculture highlights the environmental benefits and role of mariculture in improving water quality and supporting ecosystem services.

Mariculture has promise for environmental preservation and promoting economic growth and food security (Troell et al., 2023). Mariculture mitigates overfishing and protects marine biodiversity by easing the strain on wild fish stocks (Hilborn et al., 2020). Mariculture plants can also act as habitats for marine animals, fostering biodiversity and repairing damaged ecosystems. The symbiotic connection between mariculture and the environment highlights how it can support sustainable development objectives. However, it is important to acknowledge that mariculture is not without its environmental challenges and risks. The intensive farming practices associated with mariculture can lead to habitat degradation, pollution from excess nutrients and chemicals, and the transmission of diseases to wild populations (Hukom et al., 2020; Mavraganis et al., 2020; Tumwesigye et al., 2022). The escape of farmed species can also disrupt native ecosystems and introduce invasive species, posing a significant threat to local biodiversity (Alidoost Salimi et al., 2021). Moreover, the reliance on wild-caught fish for feed in certain mariculture operations can exacerbate overfishing and contribute to the depletion of fish stocks.

The benefits and challenges of mariculture are complexly intertwined. Although it provides viable answers for environmental preservation, economic growth, and food security, its adverse effects must be minimized via rigorous management and regulation. As mariculture develops as an essential part of the world's seafood industry, it can preserve marine habitats for coming generations through creativity, research, and sustainable practices. Thus, it is a vital criterion for the health of coastal zone environments.

The Bureau of Fish and Aquatic Resources (BFAR) under the Department of Agriculture (DA) is an agency that helps and monitors mariculture production in the Philippines. This agency has provincial and city offices that focus their work on their respective administrative boundaries. In this study, BFAR region XI and its corresponding cities (Davao and Mati) are the sources of this information or datasets from annual reports from 2018 to 2022.

2.2.1.8. Natural Products (NP)

This study delves into the vast array of naturally sourced marine products, highlighting their diverse origins in marine environments with minimal human alteration. These products encompass a wide range of essential items across various industries, showcasing the breadth of marine resources available for exploration and utilization. Seafood, including fish, shellfish, and seaweed, represents a cornerstone of marine-derived products and serves as a vital source of protein for human consumption (Chen et al., 2022; Tacon et al., 2020). Moreover, marine environments contribute to the production of food and supplemental ingredients, such as fish oil, which is renowned for its omega-3 fatty acids (Lobine et al., 2022), sea salt, which is used in culinary applications (Figueroa et al., 2023), and blue algae, which are rich in antioxidants and nutrients (Sansone & Brunet, 2020). The utilization of marine resources extends beyond nutrition, encompassing cosmetic and pharmaceutical compounds such as marine collagen, which is renowned for its skincare benefits, and seaweed extracts with therapeutic properties (Rigogliuso et al., 2023; Siahaan et al., 2022). Furthermore, pearls derived from marine mollusks (Cheng et al., 2021) and energy sources extracted from marine biomass add to the diverse range of naturally sourced marine products (Yang et al., 2021).

Despite the evident significance and potential of naturally sourced marine products, comprehensive data and reporting mechanisms still need to be improved. The Bureau of Fisheries and Aquatic Resources (BFAR) reports primarily focus on fish production, overlooking the broader spectrum of marine resources and their contributions to various sectors. Consequently, a critical gap exists in understanding the full extent of marine resource utilization and its implications for sustainable development. In this paper, we utilized the annual reports of the BFAR spanning from 2020 to 2023, aiming to provide a more comprehensive analysis of marine resource utilization and its implications for environmental preservation, economic growth, and food security.

2.2.1.9. Sense of Place (SP)

The sense of place concept is mainly discussed in research on the interaction between people and places (Wang et al., 2024), and the literature defines a sense of place as the significance of place to the emotional value of a person (Abou-Shouk et al., 2018; Wang et al., 2024). It is also defined as a complex emotional bond between people and a place. Sense of place has been categorized into place attachment, local attachment, place identity, and place dependence (Pretty et al., 2003; Shaykh-Baygloo, 2021).

In this study, the local attachment of tourists was explored. Local attachment acknowledges the complex associations between tourists and tourist destinations, which involve emotion, belief, and behavior, and it is argued that a sense of place plays a key role in tourists' behavioral intentions (Shaykh-Baygloo, 2021). Therefore, this paper examines local and tourists' sense of place from the perspective of impressions, emotional response, cultural engagement, environmental perception, social interactions, comparisons to home, memorable experiences, future intentions, emotional attachment, and identity. The figure below shows the framework of this study.

The survey will be performed using the questionnaires listed in Appendix Tables A8 and A9 for tourists and residents, respectively. All the questions were answered on a 5-point Likert scale ranging from strongly disagree to strongly agree. Additionally, there were questions of sociodemographic character and others eliciting outline information about each tourist's stay and the number of years of stay for the resident. Multistage probability sampling will be performed for the resident respondents. A total of 150 resident respondents will be interviewed in the selected coastal barangays of Mati and Davao City. The sample size has a margin of error of +-8% at the 95% confidence level (Bueno, 2014). On the other hand, implementing multistage random probability sampling ensures that a cross-section of citizens in the LGU is included in the sample (Bueno, 2014). The first respondent will be selected randomly from the five spot locations. These are the barangay captain's house, the house of worship, the barangay hall, the health center, and the school. Additionally, 150 tourists were selected for the nonprobabilistic sampling strategy to be cost-effective and suitable for an on-site tourist survey.

For the analysis, the structural equation model (SEM) was used to comprehensively evaluate the complex relationships among the observed and latent variables, as shown in Figure 4. SEM is widely used in behavioral science (Wang et al., 2024). Many scholars' tourists and residents have a significant impact on a sense of place (Gross & Brown, 2008; Prayag et al., 2013).

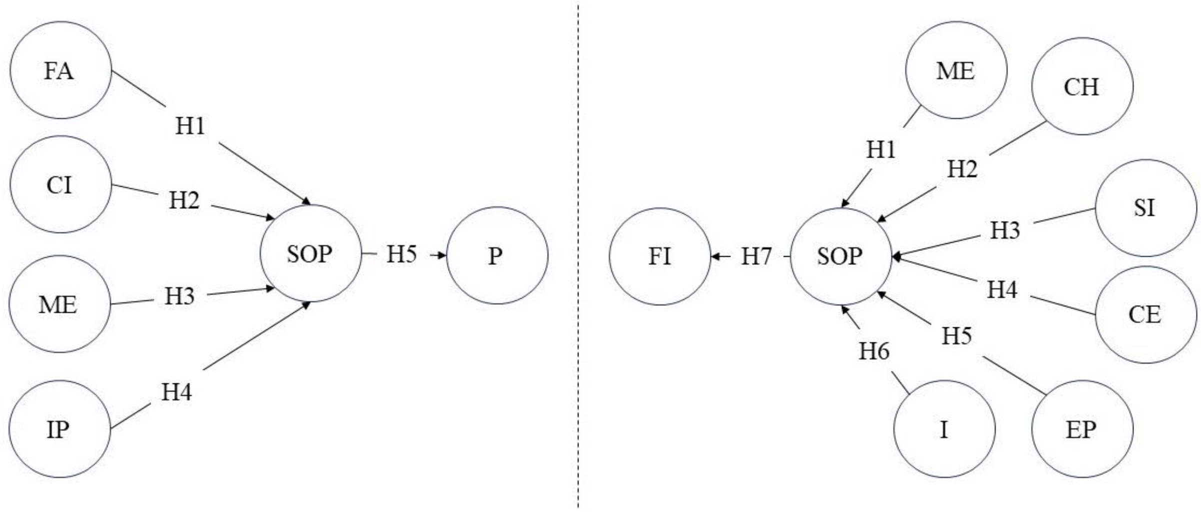

Figure 4. A conceptual framework for the sense of place. (Left: Resident, Right: Tourist)

2.2.1.10. Tourism and Recreation (TR)

Tourism is becoming the largest and strongest industry with both direct and indirect socioeconomic impacts (Tekdamar & Cengiz, 2024). It is the world's most significant sector in terms of the volume of tourists, its consequential economic influence, and its fastest-growing economic activities (Miller et al., 2002; Stoddart et al., 2020). Tourism offers employment that leads to an enhanced quality of life in the community. It indirectly enhanced business establishments such as restaurants, hotels, and resorts. It also promotes local culture and local product promotion, which triggers local development.

Sustainable tourism requires careful planning to maintain strong economies while protecting environmental and cultural resources (Aguilar-Becerra et al., 2017). It rests on three pillars: environmental, economic, and sociocultural sustainability (Tekdamar & Cengiz, 2024). Globally, sustainable tourism is a key focus of policy and research aimed at preserving nature and cultural heritage while boosting local development (Castellani & Sala, 2010). This approach involves using environmental resources wisely to ensure long-term sustainability and distribute economic benefits fairly, especially to local communities, while also enhancing tourist satisfaction (Susila et al., 2024).

Tourism and recreation, particularly in rural and coastal areas, are key for enhancing quality of life and promoting sustainable development (Utami et al., 2023). Rural tourism involves activities that showcase local life, arts, culture, and heritage, fostering interaction between tourists and locals to yield economic and social benefits (Aref & Gill, 2009). Tourism and recreation in coastal areas are essential sectors that offer a variety of activities aimed at providing entertainment, relaxation, and educational experiences for both local and international tourists (Ayhan et al., 2020). These activities range from beach activities such as swimming and surfing to cultural, local, and national events and wildlife exploration. Such tourism in scenic rural locales with diverse ecosystems boosts regional growth and sustains community life. Coastal tourism and recreation, which are also significant contributors to economic growth, leverage natural beauty and traditional lifestyles in coastal regions. This sector, evolving beyond the conventional "beach sand, swimming, and sunbathing" model, emphasizes the natural and cultural assets of coastal environments (Aref & Gill, 2009). Both rural and coastal tourism are recognized globally as strategies for economic and social development, enhancing local attractiveness and ensuring continuous improvement in tourism experiences.

The significance of coastal TR is that it acts as a substantial contributor to local and national economies through both direct revenue generation from hospitality services (i.e., hotels and accommodations) and indirect support to supplementary sectors such as agriculture and fisheries. It also serves as a key employment source, offering diverse job opportunities across various skill levels. This sector also plays a crucial role in community development, funding public services and infrastructure improvements that enhance the quality of life for residents and the tourists' experience. This sector contributes positively to sustainable development in coastal regions.

To track tourism sustainability, the Department of Tourism (DOT) records tourist arrival data and implements tourism activities in the Philippines. Mati city is known for its beautiful landscapes and seascapes and promotes cultural events annually, commemorating its cityhood, provincialhood, and traditions of the Mandaya tribes. Conversely, Davao City hosts regular annual cultural events that highlight the cultural diversity of the entire region. The local government in Davao also promotes a month-long series of traditional Christmas events.

For this study, we gathered reports from tourists at the Department of Tourism offices in Davao City and Mati City, as well as the regional DOT office. Davao City categorizes tourists into three groups: domestic, foreign, and overseas Filipino workers (OFWs), while Mati City classifies tourists as either domestic or foreign.

2.2.2. Coastal Zone Vulnerability Criteria

In the vulnerability assessment, six (6) criteria are measured for developing the coastal vulnerability index. These variables are elevation, geomorphology, sea level rise, significant wave height, shoreline change, and sea surface temperature. The criteria are ranked according to the relative resistance of a given landform to erosion. In contrast, the data values of the criteria are assigned a vulnerability ranking based on the value ranges contributing to coastal vulnerability. Each criterion input is given an appropriate risk level based on its possibility to cause very low, low, moderate, high, and very high damage, for a specific area of the coastline (Table 4). The critical factors are then combined into a single index and classified according to the relative severity of the risk to the coast. The level of each criterion and the procedure for generating the values in the CVA assessment are given in Table 4.

Table 4. Rating scale for the different parameters.

Parameters	**Very Low (1)**	**Low (2)**	**Moderate (3)**	**High (4)**	**Very High (5)**
Geomorphology(Nageswara et al., 2008; Pendleton et al., 2010)	Rocky, Cliff coast, Fjords, man-made structures	Medium cliffs, Intended coasts	Low cliffs, Glacial drift, Alluvial plains	Cobble beaches, Estuary, Lagoon	Barrier beaches, Sand beaches, Saltmarsh, Mudflats, Deltas, Coral reefs
Shoreline Change Rate (Hastuti et al., 2022)	≥ 2.1 Accretion	1.0 to 2.0 Accretion	−1.0 to 1.0 Stable	−1.1 to −2.0 Erosion	≤−2.0 Erosion
Elevation (Nageswara et al., 2008)	≥ 30	20-30	10-20	5-10	0-5
Sea Level Change rate (Hastuti et al., 2022)	≤−1.1 Land rising	−1.0 to 0.99 Land rising	1.0 to 2.0 within range of eustatic rise	2.1 to 4.0 Land sinking	≥ 4.1 Land sinking
Significant Wave Height (Hastuti et al., 2022)	< 0.55	0.55 – 0.85	0.85 - 1.05	1.05 – 1.25	>1.25

2.2.2.1. Geomorphology (G)

The creation of a map that depicts a landscape's physical characteristics and features is known as geomorphological mapping. Geomorphological features were defined from available geological maps, field investigations, and secondary data sources (Dada et al., 2024). This can include man-made and natural features, such as roads, buildings, and other structures, as well as geographic features, such as rivers, valleys, hills, and coastlines. Geomorphological mapping is frequently used in numerous disciplines, including geology, environmental science, and civil engineering. The effects of human activity on the environment, as well as the natural processes such as erosion and sedimentation that shape the landscape, can be studied. Geomorphological mapping can be carried out using various methods, such as field observations, remote sensing, topographic maps, and aerial photographs. These methods can aid in presenting a thorough and accurate picture of a location's physical characteristics and in spotting any potential changes or trends over time.

Overall, geomorphological mapping is a crucial tool for understanding the landscape and assisting in the use and management of natural resources (Reddy, 2018). The findings can guide the development of strategies for reducing these risks by assisting in identifying areas vulnerable to natural disasters such as floods or landslides. The surface type of a coastal area is referred to as coastal geomorphology. Different surface types in coastal areas react to coastal erosion in different ways. For instance, cliff coasts are less susceptible to erosion than sandy coasts. The geomorphology ranking in this study is based on the classification of Gornitz (1991) as shown in Table 4.

2.2.2.2. Shoreline Change Rate (SCR)

The shoreline change rate measures how quickly the shoreline of a body of water, such as a lake or the ocean, changes over time. It can be impacted by various factors, including human activities such as building breakwaters or removing sand and gravel from the shoreline and natural processes such as erosion and sedimentation (Colak, 2024). Shoreline changes can significantly affect the environment and coastal communities because they can result in habitat loss for animals and plants and jeopardize the stability of structures constructed close to water (Moon, 2024). Coastal managers must monitor the rate of shoreline change to predict and mitigate potential effects.

The shoreline change rate is the rate at which the shoreline erodes or accumulates due to wave action, sea level rise, or other land-affecting hazards and processes (Akhter et al., 2024). Using information from satellite imagery for 2013 (as a baseline condition) and 2023, the shoreline change rate was calculated (to describe the current conditions). The shoreline in 2013 and 2023 were compared at each grid cell along the shoreline to determine the rate of shoreline change. The rates of shoreline change are correlated with the categories of very low, low, moderate, high, and very high risk (Table 4). Shoreline change refers to the movement or alteration of the shoreline's position over time. Landward indicates erosion, and seaward indicates accretion. This event occurred naturally through human activities or a combination of both. The end point rate (EPR) is a commonly used shoreline change rate assessment method. EPR is a straightforward method for determining the shoreline change rate between the oldest and most recent shoreline positions (Kundu & Mandal, 2024; Palanisamy et al., 2024). A negative EPR indicates erosion, while a positive EPR indicates accretion. Net shoreline movement (NSM) is another way to measure the total horizontal displacement of a shoreline over a specified time (Nuray, 2024; Palanisamy et al., 2024). A positive NSM indicates accretion, while a negative NSM indicates erosion. In this study, EPR and NSM were used.

The shoreline change rate assessment involved two stages: data processing and analysis, as shown in Figure 5. The data processing involved georeferencing, image classification, and shoreline extraction. Georeferencing associates spatial coordinates (latitude and longitude) with a digital image or dataset, establishing its geographic location and alignment with a specific coordinate system (WGS84 UTM zone 51 N). This allows the image or dataset to be accurately positioned and overlaid onto a map or geographic information system (GIS) for spatial analysis, visualization, and integration with other geospatial data layers (Román et al., 2024). Image classification refers to categorizing pixels within a remotely sensed image into different land cover or land use classes (Ebenezer & Manohar, 2024; Zhao et al., 2024). This process helps in understanding and mapping the distribution of different land cover types across a landscape, which is crucial for various applications, such as environmental monitoring, urban planning, agriculture, and natural resource management. There are two main approaches to image classification in LULC. Supervised classification is one approach to image classification in LULC. It requires a training dataset with labeled samples representing different land cover classes (Aziz et al., 2024; Vinayak et al., 2021; Wang et al., 2024). These labeled samples train a classification algorithm, such as maximum likelihood, support vector machines (SVMs), or random forests. On the other hand, unsupervised classification does not rely on prelabeled training data. Instead, it automatically groups pixels in the image into clusters based on their spectral similarity without prior knowledge of land cover classes (Chen et al., 2024; Zhang et al., 2024). Common unsupervised classification algorithms include k-means clustering, ISODATA, and hierarchical clustering. After clustering, the user interprets the resulting clusters to assign land cover classes based on their spectral characteristics and spatial patterns.

This study utilized unsupervised image classification, and only two classes were specified (i.e., water and land). The shoreline between the two classes is displayed. The results were converted into line segments for shoreline extraction. We extracted two shorelines from Landsat OLI 8 for 2013 and 2023, as shown in Figure 6. Therefore, the result is a 10-year average change. The second stage involves the assessment of the EPR program and NSM. The shoreline change was analyzed using the Digital Shoreline Analysis System (DSAS. DSAS uses a baseline to calculate shoreline change metrics based on transects cast at 200 m intervals along the shoreline, and a confidence interval (95%) was applied when determining shoreline change rates (Carruthers et al., 2023).

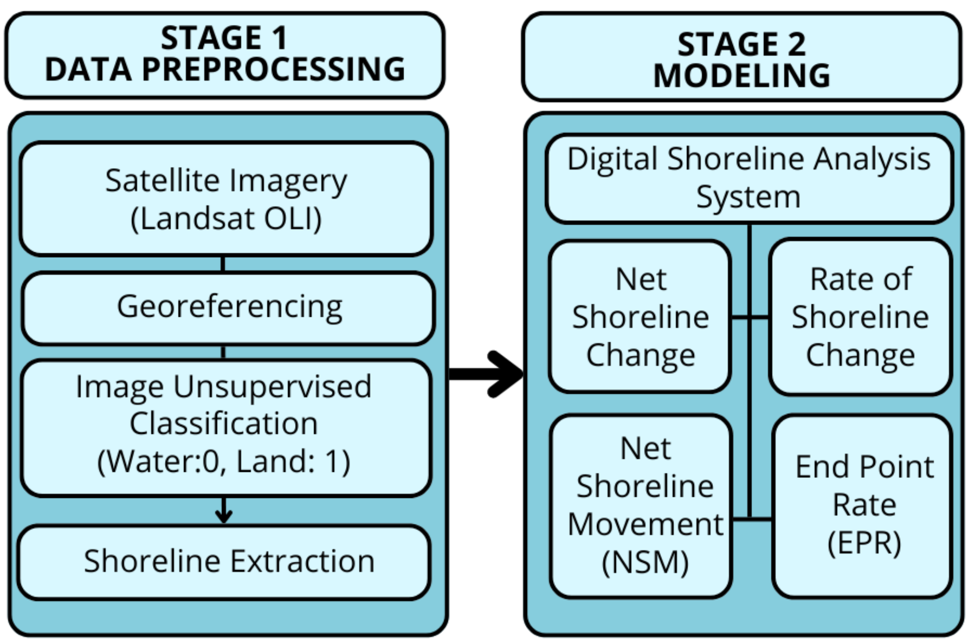

Figure 5. Flowchart of the shoreline change rate assessment.

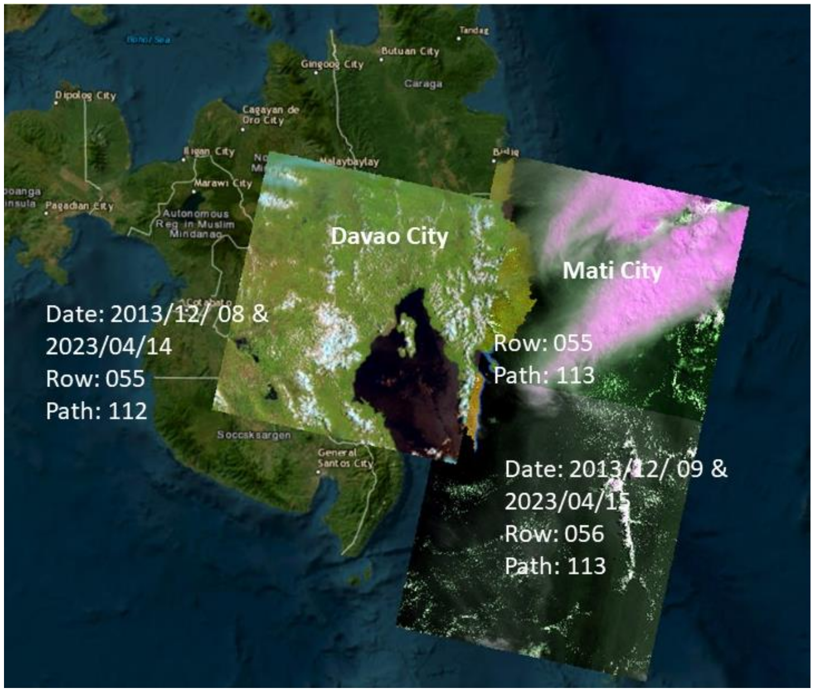

Figure 6. The Landsat OLI 8 satellite image of the two study areas.

2.2.2.3. Sea Level Change Rate (SLCR)

Climate change impacts lives in coastal communities (Gill et al., 2023). Moreover, profound sea level rise (SLR) can eventually cause coastal inundation and thus can damage coastal ecosystems and the environment, including coastal economic activities (Doelle & Puthucherril, 2023). Global SLR is a consequence of global warming as it warms and is a result of the melting of ice from glaciers and ice sheets, representing the sustained elevation of Earth's oceans and coastal waters (Durand et al., 2022). The thermal expansion of seawater as it absorbs heat due to rising global temperatures and the mixing of water from melting ice sheets and glaciers in polar regions are the primary reasons for SLR phenomena (IPCC, 2021). Since the early 1900s, the global mean sea level (GMSL) has risen approximately 3 mm per year (Dieng et al., 2017), with a recent notable acceleration in the rate of rise, and future projections indicate continued acceleration (Oppenheimer et al., 2019).

In a global context, it is important to recognize that the SLR is nonuniform across all regions and needs to be understood to provide meaningful scenarios and solutions (Durand et al., 2022). There is considerable variation in the pace at which sea level is increasing in different parts of the world. For example, in Church et al. (2006), the average rate of SLR in the Pacific Ocean from a satellite altimeter was approximately 4 mm per year from 1993 to 2001. Moreover, Church et al.

(2006) stated that some areas in the Maldives are experiencing SLR, ranging from 3.7 mm to 8.4 mm per year. Another study showed that the rate of sea level change in the Arctic Ocean from 1950–1985 was estimated to be between 0.02 and 0.06 mm per year (Proshutinsky et al., 2001). Furthermore, Ohenhen et al. (2001) used satellite data from 2007 to 2020 to show that the U.S. Atlantic coast is experiencing SLR at a rate of 3.35 mm/year due to local land subsidence. Along the Australian coastline, the estimated change in relative mean sea level for the period from 1920 to 2000 was approximately 1.2 mm per year (Church et al., 2006). These studies showed that local SLRs occur in Mati and Davao City.

Sea level change refers to the variations in the average height of the Earth's oceans over time and is driven by factors such as the thermal expansion of seawater, the melting of glaciers and ice sheets, and changes in land water storage (Church & White, 2011). The rate at which the sea level changes over time is referred to as the sea level change rate. Numerous factors can affect this process, such as human activities such as burning fossil fuels and deforestation, as well as natural processes such as melting glaciers and thermal expansion. Since rising sea levels can result in flooding and the loss of coastal habitats, while falling sea levels can expose previously submerged areas, sea level change can significantly impact the environment and coastal communities. Scientists must monitor sea level change to comprehend its causes and anticipate its future effects. Satellite measurements, tide gauges, and simulations of the ocean and its interactions with the Earth's climate system are some of the tools used to measure sea level change.

The observed sea levels were obtained from the Permanent Service for Mean Sea Level (PSMSL) (https://psmsl.org/). The records from the last two decades, 2000 to 2020, were used to evaluate the sea level trend in the study areas. The missing values vary by station. To address the missing data, several imputation methods were tested. A complete illustration of the data imputation procedure is provided in the following paragraphs.

This paper applied time series analysis using the ICEEMDAN dataset. EMD is a variant of empirical mode decomposition (EMD). EMD is a data-adaptive modal decomposition method that extracts oscillatory patterns (i.e., lower instantaneous frequencies), creating intrinsic mode functions (IMFs) (Park & Sweet, 2015). Unlike other methods such as Fourier decomposition or wavelet transforms, EMD is adaptive and recursive, making it suitable for nonstationary and nonlinear data analysis. It can effectively capture time-adaptive trends. However, EMD has limitations, including mode mixing, where different IMFs may contain parts of signals with the same temporal scale (Park & Sweet, 2015). The limitations of EMD include the use of ensemble empirical mode decomposition (EEMD). EEMD can decompose the noise ensemble copy of the original signal, resulting in an ensemble average. EEMD uses noise to help reduce the effect of mode aliasing(Jin et al., 2023) The EEMD algorithm can cause additional mode-splitting problems (Lang et al., 2020). Therefore, Colominas et al. (2014) proposed the CEEMDAN algorithm, which has proven to be a significant development of EEMD (Andari et al., 2023) and effectively addresses issues related to reconstruction errors and varying mode counts among signals and noise realizations. However, CEEMDAN introduces residual noise in the modes and spurious modes. The ICEEMDAN focuses on solving residual noise and spurious mode problems, as well as mode mixing issues, from the result of CEEMDAN, which yields better and more meaningful results than the successor EMD variants. The CEEMDAN and ICEEMDAN algorithms are described in the study of Colominas et al. (2014, p. 20). The readers are also advised to read the study of Huang and Wu (2008) for a complete discussion.

Figure 7 depicts the procedural application of the sea level analysis in this study. The sea level observation data are the input data for the ICEEMDAN algorithm. Monthly raw data were extracted from the PSMSL for the period from 2000 to 2020. The missing values vary at every tide station. Several imputation methods were tested to fill in the missing values. These methods include mean linear interpolation, last observation carried forward (LOCF), next observation carried backward (NOCB), seasonally decomposed missing value imputation (SEADEC), seasonally split missing value imputation (SEASPLIT), k-nearest neighbors (KNN), and long short-term memory (LSTM). The mean method replaces the missing value with the sample mean (Waljee et al., 2013). Linear interpolation is a method used to estimate missing values in a data sequence by employing a linear equation (Junninen et al., 2004). Furthermore, the LOCF fills in missing data in time-series datasets from the last observation before the missing value (Ahn et al., 2022). Conversely, the imputation by NOCB is a method that uses the first observation after the missing value in a time series (Ahn et al., 2022). On the other hand, the SEADEC dataset is a method used in seasonal time series data analysis (Ahn et al., 2022). This approach involves decomposing the time series into its constituent components, imputing missing values, and reconstructing the series. SEASPLIT also applies to explicit seasonal time series datasets. This approach is useful when the missing data are not random but rather have a seasonal trend (Ahn et al., 2022). The KNN approach uses the k-nearest neighbors strategy to replace missing dataset values with the mean of the closest 'n neighbors' from the training set. The Euclidean distance metric is employed as the standard for this imputation process (Zhang, 2012). Finally, LSTM imputation involves training an LSTM network on the available time series data, allowing it to learn the underlying patterns and dependencies. Once trained, the network can be used to predict missing values in the time series observation data.

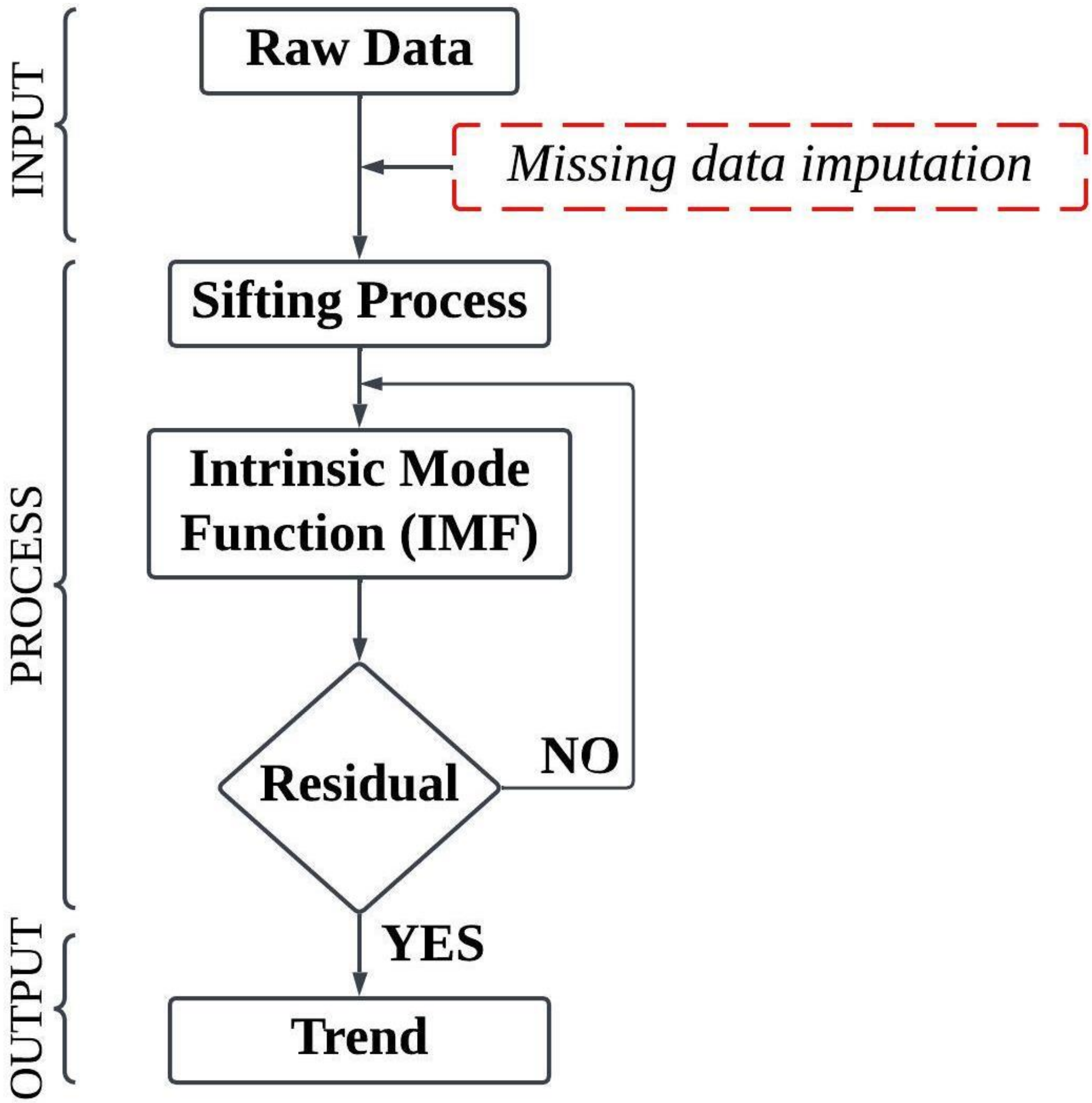

Figure 7. Framework for the sea level rise analysis

The complete dataset with no missing data was used in the ICEEMDAN analysis after identifying the most accurate imputation method. ICEEMDAN employs the sifting process to break down sea level observations (i.e., considered a signal in this method) into IMFs. The IMF represents an oscillatory mode with variable amplitude and frequency, in contrast to harmonic functions with constant amplitude and frequency. The sifting process will continue until the residual is obtained. The residual typically consists of the remaining components in the data that do not display a distinct oscillatory pattern and are often regarded as trend components. In this study, the rate of SLR is computed based on the trend extracted from this residual component, after which the sea level change rate and assigned risk ratings are calculated.

2.2.2.4. Elevation (E)

Elevation is an essential factor to consider in vulnerability assessments of coastal areas because it can be used to detect areas at risk of flooding or erosion due to sea level rise or storm surges. Coastal elevation is defined as the average height of an area above mean sea level (Canul Turriza et al., 2024). Coastal areas with higher elevations are generally considered less vulnerable to these types of impacts, as they are less likely to be inundated by rising water levels. On the other hand, low-elevation coastlines are more vulnerable to flooding and erosion and may be more susceptible to damage from these types of events. In addition to helping to identify vulnerable areas, elevation data can also be used to estimate the potential extent of land threatened by inundation and to identify the impacts of sea level rise on human populations and infrastructure.

A digital elevation model (DEM) refers to a digital map representing the Earth's surface derived from contour lines or photogrammetric techniques. The coastal elevation is obtained by processing the DEM data, and the elevation values are categorized based on the vulnerability indices, as shown in Table 3. Higher-elevation coastal areas are thought to be less vulnerable because they are less likely to be flooded by storm surges or sea level rise. As a result, lower-elevation coastlines are highly susceptible to erosion and flooding. The coastal elevation predicts both the potential speed of shoreline retreat and the relative risk of inundation. To approximate coastal vulnerability, coastal elevation must be measured along with coastal morphology. In several CVA studies, coastal elevation has been used to illustrate the vulnerability of coastal zone areas due to inundation, replacing coastal slopes (Gornitz, 1991).

2.2.2.5. Significant Wave Height (SWH)

Waves are generally the main hydrodynamic force in coastal areas and continuously interact with shoreline erosion or accretion (Ghaderi & Rahbani, 2024). Thus, wave height data is an vital for describing shoreline vulnerability (Ghaderi & Rahbani, 2024). High waves can cause erosion of the shoreline. Intense waves can also damage or destroy coastal structures such as buildings, roads, and bridges and pose a hazard to people and animals in the affected area. In addition, strong waves can cause coastal flooding by pushing water onto land or increasing wave heights (Łabuz, 2015). This information can help coastal managers anticipate and plan for the potential impacts of high waves onshore shorelines and coastal communities. Additionally, other studies, such as those by Dickson et al. (2021), have emphasized the role of seasonal and climatic variations in wave intensity and their consequent effects on coastal erosion rates. Recent findings by Aldehim et al. (2024) also discuss how decisive wave actions contribute to coastal flooding by direct inundation or by enhancing the water's overtopping capabilities. This knowledge is instrumental for coastal managers in planning and implementing effective mitigation strategies to safeguard coastal communities against the adverse impacts of high waves, enhancing both human safety and structural resilience.

ERA5 is the fifth generation of the reanalysis dataset of the European Center for Medium-Range Weather Forecasts (ECMWF), which provides a comprehensive dataset that includes significant wave height, among many other meteorological, land, and oceanic parameters (Du et al., 2024). Since 1979, the ERA5 reanalysis has provided hourly data on a wide range of atmospheric and oceanic phenomena, including wave heights, in nearly real time. ERA5's significant wave height data are obtained from a combination of model data and observations, including satellite measurements, buoy data, and other marine observations. This integration contributes to the correctness and reliability of the data. The significant wave height is defined as the average height (trough to crest) of the top third of the waves (Hs) for a certain period, which is usually 20 minutes to an hour. This metric is critical for understanding and assessing wave conditions around the world, especially for marine and coastal applications. The ERA5 significant wave height data are widely used in a variety of applications. These include marine forecasting (Liu et al., 2024), coastal engineering (Juan et al., 2024), maritime safety (Juan et al., 2024), and climate research (Casas-Prat et al., 2024). For example, it aids in determining the risk and potential consequences of coastal floods, erosion, and other marine hazards.

The significant wave height data are an important resource for studying and monitoring marine and coastal habitats, enabling not only daily weather forecasts but also long-term climate studies and environmental assessments. Thus, this paper utilized the ERA5 significant wave height data to determine the changes in waves from 2000 until 2023.

2.2.2.6. Sea Surface Temperature (SST)

The sea surface temperature (SST) is fundamentally important for understanding changes in the Earth's climate (Bulgin et al., 2020). Several approaches for observing SSTs are remote sensing, in situ observation, bouy, and reanalysis methods. The sea surface temperature is an essential factor to consider in coastal vulnerability assessments because it can significantly impact physical and biological processes in coastal zones. Changes in sea surface temperature can affect the distribution and abundance of marine species and the health of coral reefs and other coastal habitats (Petsas et al., 2022). In addition, sea surface temperature can influence the intensity and frequency of storms and other extreme weather events, which can directly and indirectly impact the shoreline and coastal communities (Lavender et al., 2018). When assessing the vulnerability of a coastal area, it is vital to consider not only the current sea surface temperature but also the potential for future changes in temperature due to climate change or other factors. This information can help coastal managers anticipate and plan for the potential impacts of sea surface temperature changes onshore shorelines and coastal communities.

Understanding and monitoring changes in sea surface temperature are crucial for effective coastal management and climate adaptation strategies. Accurate SST data, as provided by ECMWF-ERA5, enable policymakers and researchers to develop predictive models and risk assessments that can guide conservation efforts and infrastructure planning. By integrating historical SST data, coastal managers can better prepare for and mitigate the impacts of climate change on marine ecosystems and coastal communities. Such proactive measures are essential not only for safeguarding biodiversity but also for protecting the economic stability and safety of coastal populations. Through continued research and enhanced monitoring of SSTs, strategies can be refined and adapted to ensure the resilience of coastal regions in the face of environmental changes.

Daily sea surface temperature reanalysis datasets were obtained from the ECMWF-ERA5 data on a 0.5^0 grid from 2000 to 2023. The daily reanalysis dataset was used in the decomposition process using ICEEMDAN. A complete description of ICEEMDAN is provided in subsection 2.2.2.3. The residual or trend from the result of the ICEEMDAN was used to quantify the SST trends in the specified period. The datasets were then reclassified for risk assessment according to grid cells in the coastline areas of Davao and Mati city.

Chapter 3 - Methodology

3.1. Multicriteria Decision Analysis

Environmental resource planning is a critical aspect of sustainability assessment where societal development and nature coexist. A thorough evaluation of a sustainable resource assessment would not only address the requirement for the local government to establish a process that safeguards the environment but also aid in directing decision-makers while enacting sustainable resource policy. The book written by Beinat (2002) described three methodologies to support the decision-making process for environmental and resource planning. These methodologies include benefit-cost analysis (BCA), cost-effectiveness analysis (CEA), and multicriteria decision analysis (MCDA). Therefore, this paper's technique focuses on comprehending how policymakers see the environment when constructing sustainable policy utilizing expert-driven multicriteria decision analysis. Figure 8 illustrates the top-down multicriteria decision analysis methodology of this study. The goal is to develop an adaptive framework to assess the health and integrity of the coastal zone environment. The first step of this approach is to determine the decision maker's perception of being one of the criteria (i.e., conservationist, non-extractive, extractive, or strongly extractive, which are defined below) for the city development plan.

- A conservationist (C) is the act of seeking the proper use of environmental resources.
- Nonextractive (NE) is an act of utilizing the services of the environment without extraction. Eco-tourism is an example of this concept.
- Extractive (E) is an act of obtaining natural resources.
- Strongly extractive (SE) is an act of over-extraction that can cause the depletion of natural resources.

In this study, the design of the CoZHI framework is based on the societal views of the decision-makers using the MCDA-AHP. The following are the steps to generate the framework. First, identify the criteria (i.e., C, E, NE, and SE). The four criteria were adapted and modified from the study of Halpern et al. (2012). In the OHI framework, the weights that are applied to the 10 goals (i.e., indicators in this paper) to calculate the index score were assumed to be equal, even though this assumption does not reflect across all stakeholders in the community. Furthermore, Halpern et al. (2012) address this limitation by designing four different weight schemes that represent preservationist, extractive, non-extractive use, and strongly extractive use (see Table S4 from Halpern et al. (2012)). The OHI framework illustrates that the country can be assessed in one of these four schemes. Unfortunately, this did not address the stakeholders' perspective but rather still the author's perception. The weights in every criterion in the scheme might differ for every stakeholder. Thus, this paper tries to obtain every stakeholder's perspective using MCDA-AHP in their views of their own coastal city. The second step is to determine the coastal risk assessment using six parameters. The six parameters are, coastal elevation, geomorphology, sea surface temperature, sea level rise, shoreline change, and significant wave height. The third step is to generate the weighted health index framework using the ten indicators. Last, the final integrated coastal zone health index score includes three cases. The first case is the average score of the CRA and CVA. In the second case, the CRA score is highly important. The third case is giving high importance to CVA. Case 2 and 3 are generated using the MCDA-AHP. Sub-section 3.6 described the framework generation for the two cases. The developed index framework is a tool for assessing the health and integrity of coastal zone environments. Table 5 presents the definition of all indicators, while Table 6 presents the six parameters of the coastal vulnerability index assessment.

This paper implemented a purposive sampling approach, where the target respondents are the employees in the city local government unit (LGU). There are three levels of the local government in the Philippines. They are provinces and independent cities, component cities and municipalities, and barangays (village). In this study, the study areas are independent cities. The respondents are planning officers, administrators, management officers, economists, city engineers, and academicians and researchers in the field of environmental studies. This inclusion of respondents can provide recommendations regarding the design of the city's coastal zone management plan.

Table 5. Definition of the CRA framework indicators.

Datasets	Definition
Biodiversity (B)	The existence value of biodiversity is calculated by the protection status of marine-related species.
Carbon Storage (CS)	Conservation of coastal habitats utilizing carbon storage and sequestration.
Coastal Livelihood (CL)	Coastal and marine-related livelihood activities.
Coastal Protection (CP)	Protection of the coastal areas (e.g., mangrove forests protect coastal areas from erosion).
Clean Water (CW)	Water free from detrimental nutrients, chemical pollution, marine debris, and pathogens.
Fisheries (F)	Harvest of sustainable seafood from ocean wildlife engaging in artisanal-scale fishing
Marine Culture (MC)	Cultivation of seafood in the coastal zone.
Natural Products (NP)	Naturally produced sea products.
Sense of Place (SP)	Cultural, spiritual, or aesthetic relationships are associated with iconic species and the environment.
Tourism and Recreation (TR)	Cultural, spiritual, or aesthetic relationships are associated with iconic species and the environment.

Table 6. The definition of the CVA criteria.

Parameters	Definition
Geomorphology	The surface type of the coastal area. This can include man-made and natural features, such as roads, buildings, and other structures, as well as geographic features, such as rivers, valleys, hills, and coastlines.
Shoreline Change	It is the changes at which the shoreline erodes or accumulates due to wave action, sea level rise, or other land-affecting hazards and processes (Akhter et al., 2024).
Elevation	Coastal elevation is defined as the average height of an area above mean sea level (Canul Turriza et al., 2024).
Sea Level Change	It refers to the variations in the average height of the Earth's oceans over time and is driven by factors such as the thermal expansion of seawater, the melting of glaciers and ice sheets, and changes in land water storage (Church & White, 2011)
Sea Surface Temperature	Changes in sea surface temperature can affect the distribution and abundance of marine species and the health of coral reefs and other coastal habitats (Petsas et al., 2022).
Significant Wave Height	Waves are generally the main hydrodynamic force in coastal areas and continuously interact with shoreline erosion or accretion (Ghaderi & Rahbani, 2024)

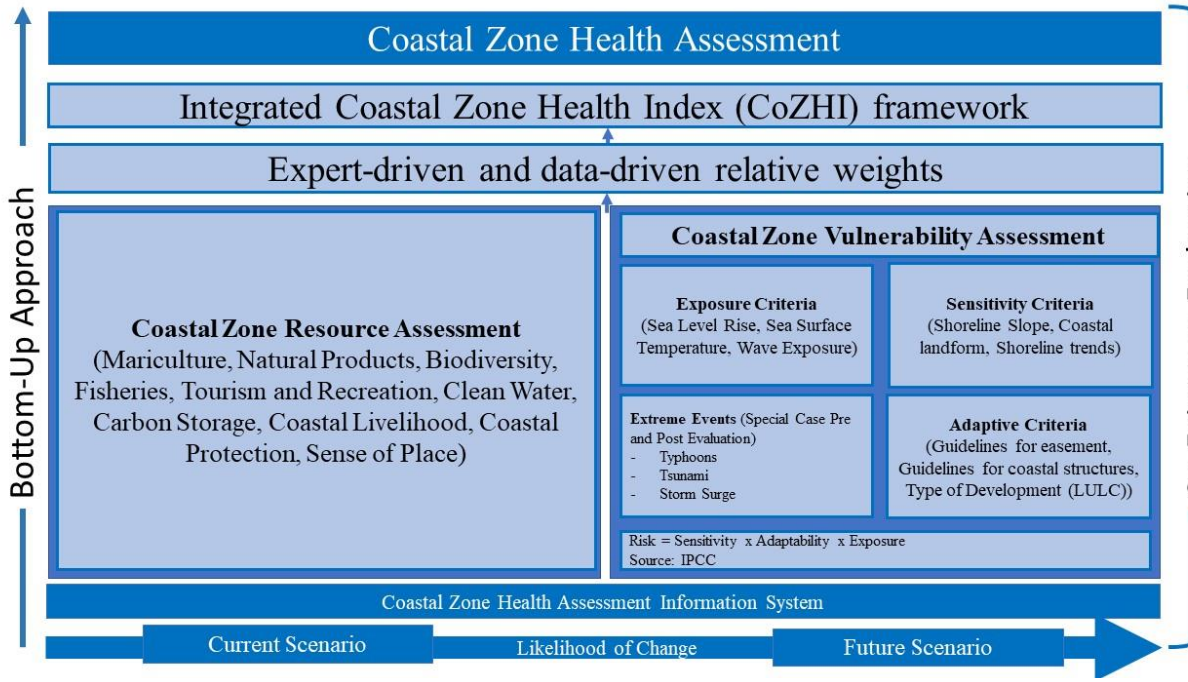

Figure 8. Adaptive and integrated CoZHI and CVA framework in designing flexible resource assessment.

3.2. Framework of using Analytical Hierarchy Process

The pairwise matrix is the 1st step in this method, where each criterion is compared to another using the Saaty scale (Saaty, 1980). Policymakers provide their judgments of the relative importance of one criterion or indicator against another. A higher relative number means that the indicator or criterion is more important than the other indicator or criterion.

The 2nd step is the normalization. In this step, each value in the pairwise matrix (C_{ij}) is divided by the sum of each column to obtain the normalized value (X_{ij}) (see Equation 1). The value in the normalization matrix is a percentage value from the first matrix.

$$X_{ij} = C_{ij} \,/ \sum_{i=1}^{n} C_{ij} \tag{1}$$

The next step is to generate the relative weight (W_{ij}) of each criterion or indicator by dividing X_{ij} by the number of criteria or indicators (n), as shown in Equation 2.

$$W_{ij} = \sum_{i=1}^{n} X_{ij}/n \tag{2}$$

The last part of the AHP procedure is consistency ratio analysis. There are three substeps in this part. The 1st step is to calculate the consistency measure (CM), which can be obtained by multiplying the pairwise matrix by the relative weight. The result is divided into a weighted sum vector with criterion or indicator weights (Cabrera & Lee, 2018) . The 2nd step is to calculate the consistency index (CI), as shown in Equation 3. The λmax is the average of the CM. Finally, the consistency ratio (CR) is computed using Equation 4 below. The relative index (RI) values are shown in Table 8.

Table 7. Random index (RI) with its corresponding value.

Criteria	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

3.3. Coastal zone resource assessment (CRA) score

The generation of the coastal zone integrity index score was based on the OHI framework developed in section 2.3.2. Halpern et al. (2012) applied an equal weight to every criterion, as shown in Equation 3, where N is the number of criteria and C_i is the score of the i^{th} criterion. In contrast, in this study, each criterion has a weight, and the weight of each criterion is different in every city, as shown in Equation 4.

$$I = 1/N \sum_{i=0}^{N} C_i \tag{3}$$

$$I = \sum_{i=0}^{N} (C_i * W_i) \tag{4}$$

3.4. Individual criterion score

Every criterion has a score generation based on Equation 5, where the present status of criterion C_i is its present value X_i relative to a reference point X_i^R, uniquely chosen for each goal and rescaled from 0–100. The reference points of each criterion are listed below:

$$C_i = \frac{X_i}{X_i^R} \tag{5}$$

- Mechanistic Estimates: These are based on production functions, such as the max/mean sustainable yield*,* for example, the fisheries to determine the optimal or sustainable level of a resource or activity.
- Spatial Comparisons: In some cases, reference points are established through comparisons with other countries/cities/regions. For example, the highest-ranked country/city/region with a particular goal may represent the best possible known case.
- Temporal Benchmarks: These use a past benchmark as the reference point, such as historical habitat extent. This could be a fixed point in time.
- Known or established targets: These reference points are based on specific known values or established targets. For instance, a reference point for pollution might be zero (indicating no pollution) or for marine protected areas.

3.5. Coastal zone vulnerability assessment (CVA)

The current study will employ an index-based methodology, specifically the coastal vulnerability index (Hastuti et al., 2022). In the vulnerability assessment, six (6) criteria are measured for developing the CVA. These variables are elevation, geomorphology, sea level rise, significant wave height, shoreline change, and sea surface temperature. The criteria are ranked according to the relative resistance of a given landform to erosion. In contrast, the data of the criteria are assigned a vulnerability ranking based on the value ranges contributing to coastal vulnerability. Each criterion input is given an appropriate risk level based on its possibility of causing very low, low, moderate, high, or very high damage for a specific area of the coastline. The critical factors are then combined into a single index and classified according to the relative severity of the risk to the coast.

The CVA analysis will be carried out using a GIS application that generates geospatial information. The CVA uses a formula to combine the key parameters into a single index after assigning a risk value to each section of the coastline. Equation 6 shows that the CVA is calculated by taking the square root of the average of the ranked parameters.

$$CVA = \sqrt{\frac{SST+E+SLCR+W+G+SCR}{N}} \tag{6}$$

where SLCR is the risk rating assigned to sea level change rate; E is the risk rating assigned to elevation; SST is the risk assigned to sea surface temperature; WS is the risk rating assigned to significant wave height; G is the risk rating assigned to geomorphology; and finally, the SCR is the risk rating assigned to shoreline change rate. The CVA is classified into five ranges. The lowest range will be assigned very low vulnerability, followed by low, moderate, high, and very high vulnerability.

3.6. Final framework for the CoZHI assessment

The integration of the CRA and CVA is the last component of this study. The CRA is a measure of the productivity of the coastal zone environment. Moreover, the CVA is used to assess the susceptibility of coastal zone areas to hazards. The final integrated coastal zone framework health index score includes three cases. The first case is the average score of the CRA and CVA as shown in Equation 7. In the second case, the CRA score is highly important. The third case is giving high importance to CVA. Case 2 and 3 are generated using the MCDA-AHP as defined in Equation 8, where W is the weight of the CRA and CVA.

$$CoZHI = (CRA\,score + CVA\,score)\,/\,2 \tag{7}$$

$$CoZHI = (W * CRA\,score + W * CVA\,score) \tag{8}$$

Unfortunately, the two have different units. The CRA is expressed as a percentage, while the CVA is a categorical value representing risk ratings. One common technique for normalizing categorical data is one-hot encoding. Each category has a binary indicator. A value of 1 is assigned for the category to which the observation belongs, and 0 is assigned for all other categories. The risk ratings for each category are as follows; Very low [1,0,0,0,0], Low [0,1,0,0,0], Moderate [0,0,1,0,0], High [0,0,0,1,0], and Very High [0,0,0,0,1].

The values of each category are assumed to be 100%, 80%, 60%, 40%, and 20% for Very Low, Low, Moderate, High, and Very High, respectively. The variance in each category is 20%. Equation 9 is used to convert the risk index rating into a percentage value, where Hc is the hotspot value, V is the variance with a constant value of 20, and Hr is the remaining decimal value in the original index rating.

$$CVA\,(\%) = Hc - (V * Hr) \tag{9}$$

Chapter 4 - Coastal Resource Assessment

This section represents the culmination of our comprehensive research and is especially significant because it reveals the health index scores of coastal cities, with a particular emphasis on the Philippines. The health index score is an important metric that measures the overall health and well-being of coastal ecosystems. We chose Mati city and Davao City as the focal points of this study due to their relevance and representation of coastal cities in the Philippines. These cities were chosen because of their distinct coastal characteristics, demographic compositions, and varying levels of urbanization, which together provide a comprehensive picture of coastal health in the Philippines. The computation of the health index score for each city was meticulously carried out using two distinct equations: Equation 8 for Mati city and Equation 9 for Davao City, as derived in Section 3.1.

4.1. Mariculture criterion score

Mariculture (MC) involves the cultivation of seafood, such as fish, shellfish, and seaweed, in coastal zone areas, utilizing the natural environment and resources to enhance production and sustainability. Mariculture cultivates seafood in coastal zone areas. There are several fish and seaweed cultivation plants in the Philippines. Davao City cultivates milkfish, catfish, seaweeds, and tilapia. In Mati city, milkfish, catfish, pompano, seaweed, shrimp, parrotfish, and tilapia are cultivated. Pictures are shown in Figure 9. Most cities and Filipinos cultivate milkfish, as this fish is the national fish in the Philippines, and the government supports it. Tilapia is the second most cultivated fish since it is not delicate and easy to maintain. The Bureau of Fish and Aquatic Resources (BFAR) under the Department of Agriculture (DA) is an agency that helps and monitors mariculture production in the Philippines. This agency has provincial and city offices that focus their work on their respective administrative boundaries. In this study, the BFAR region XI and its corresponding cities (Davao and Mati) are the sources of this information or datasets from yearly reports from 2018 to 2022.

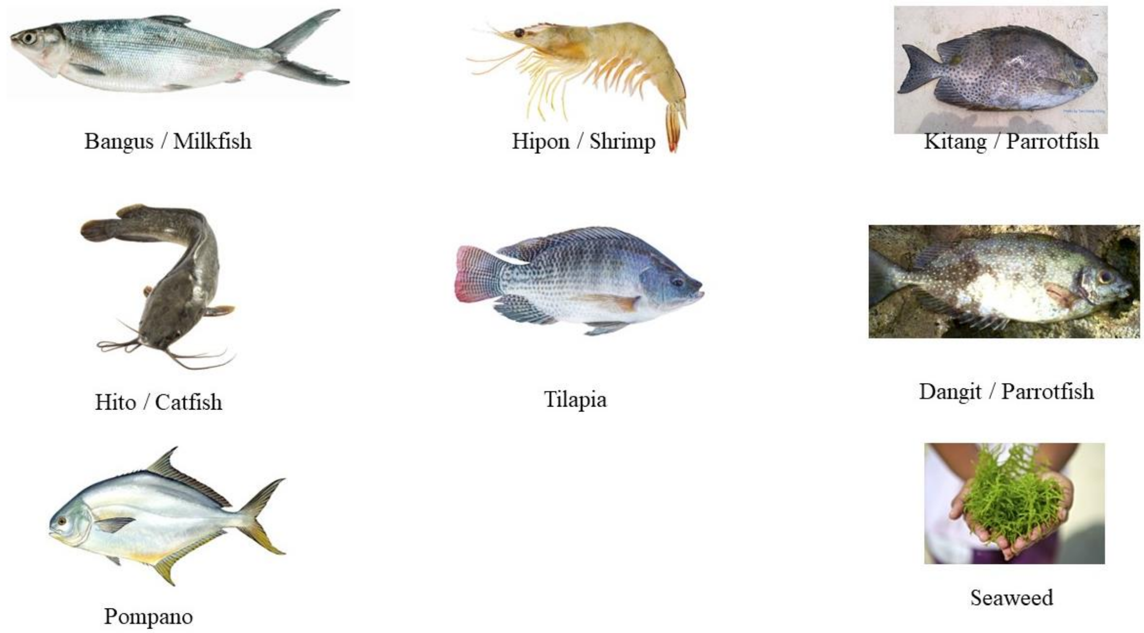

Figure 9. Type of mariculture production.

Table 9 outlines the mariculture production in Davao and Mati city, providing a basis for calculating the health index score using Equation 4. This process involves normalizing the yearly production figures, with the resulting average normalized score serving as this year's health score and a reference point for future assessments. For Davao City, the normalized scores for 2018 to 2021 are 0.0, 0.1193, 0.1131, and 0.3732, respectively, leading to an average health score of 32.11%. In contrast, Mati City's normalized scores for 2018 to 2020 are 0.3284, 0.0, and 1.0, yielding an average score of 44.28%. These scores provide a quantifiable measure of the contribution of mariculture productivity to the health index of each city.

Table 8. Mariculture production in metric tons.

Production	**2018**		**2019**		**2020**		**2021**		**2022**	
	Davao	**Mati**	**Davao**	**Mati**	**Davao**	**Mati**	**Davao**	**Mati**	**Davao**	**Mati**
Bangus (Milkfish)	452.45	20.05	774.5	39.4	826.3	124.7	1534.8	-	860.95	-
Hito (Catfish)	194.58	0.44	224.13	-	236.64	-	253.54	-	314.76	-
Pompano	-	4.06	-	16	-	-	-	-	-	-
Seaweeds	90.97	14.3	80.42	43.68	6.03	-	23.12	-	2446.1	-
Shrimp	-	131.54	-	-	-	254.77	-	-	-	-
Kitang/Dangit (Parrotfish)	-	0.66	-	1.08	-	5.59	-	-	-	-
Tilapia	11.42	27.38	17.43	7.01	9.57	0.02	23.55	-	36.4	-
TOTAL	**749.4**	**198.4**	**1096.5**	**107.2**	**1078.5**	**385.1**	**1835.0**	**-**	**3658.2**	**-**

4.2. Fishery criterion score

Fisheries, defined as seafood harvested from ocean wildlife through artisanal-scale fishing, are a crucial component of coastal economies. The data for this analysis were sourced from annual reports by BFAR Region XI and local government offices in Mati city and Davao City. However, it is important to note that BFAR data are available only from 2020 to 2022. Table 10 illustrates the annual fish production in both cities, highlighting a slight increase in Davao City's catch over the years, which contrasted with a significant surge in Mati city's fish catch in 2021. This surge is attributed to a bountiful tuna harvest, a fishery for which Mati city is renowned in the Philippines. The tuna caught in Mati city was sold in General Santos city, home to numerous tuna canneries and a hub for tuna export. The COVID-19 pandemic and subsequent lockdowns shifted this dynamic, with all tuna sales confined within the city.

Unlike mariculture, there are no established benchmarks for acceptable fish production levels in the Philippines. Therefore, this study adopted a min–max normalization method to calculate the health index score from fish production data. The average normalized scores were 56.88% for Davao City and 33.44% for Mati city, reflecting the impact of fishery productivity on the overall health score of each city.

Table 9. Fishery production in metric tons.

Year	Davao	Mati
2020	89.18	255.14
2021	91.32	68,630.76
2022	92.21	38.09
TOTAL	**749.42**	**198.43**

4.3. Water quality criterion score

Sea water quality assessment is vital for understanding the health of marine ecosystems, the safety of human activities in marine environments, and the potential impacts of anthropogenic activities on the ocean. Figure 10 shows the survey points in the two cities. The Hanna H191814, multiparameter water probe, and echo sounder Garmin GPS 585 were used during the survey. The parameters tested in this study were dissolved oxygen (DO), salinity (S), total dissolved solids (TDS), and acidity (pH). The survey was conducted last in April and May of 2023. There are 15 sample survey points for Davao City, 36 in Pujada Bay, Mati City, and 14 in Mayo Bay facing the

Pacific Ocean. The basis of the score is Department Order 34 of the Department of Environment and Natural Resources (DENR DAO 34). The acceptable DO concentration is 7.0–8.0 mg/L. The TDS is < 39 mg/L, the salinity is between 33 and 38 ppt, and the acceptable pH is 6.5-8.5. A summary of the survey results is shown in Table 10. The average health score of Mati is 0.97 or 97%, which means that the water quality of Mati City, in general, is acceptable based on the DENR DAO 34 guidelines. Unfortunately, there are areas to be constantly monitored. Those areas are high or above the standards for shrimp production. This is due to the release of water from the fishpond with this concentration of inorganic feed and fertilizers. The average score for Davao City is 0.89, or 89%. The pH and DO levels of Davao City are high, which causes a low overall result. This result might be biased due to the survey schedule. This is a limitation of this study. Thus, it is necessary to conduct a monthly survey to obtain yearly average water quality sample reports.

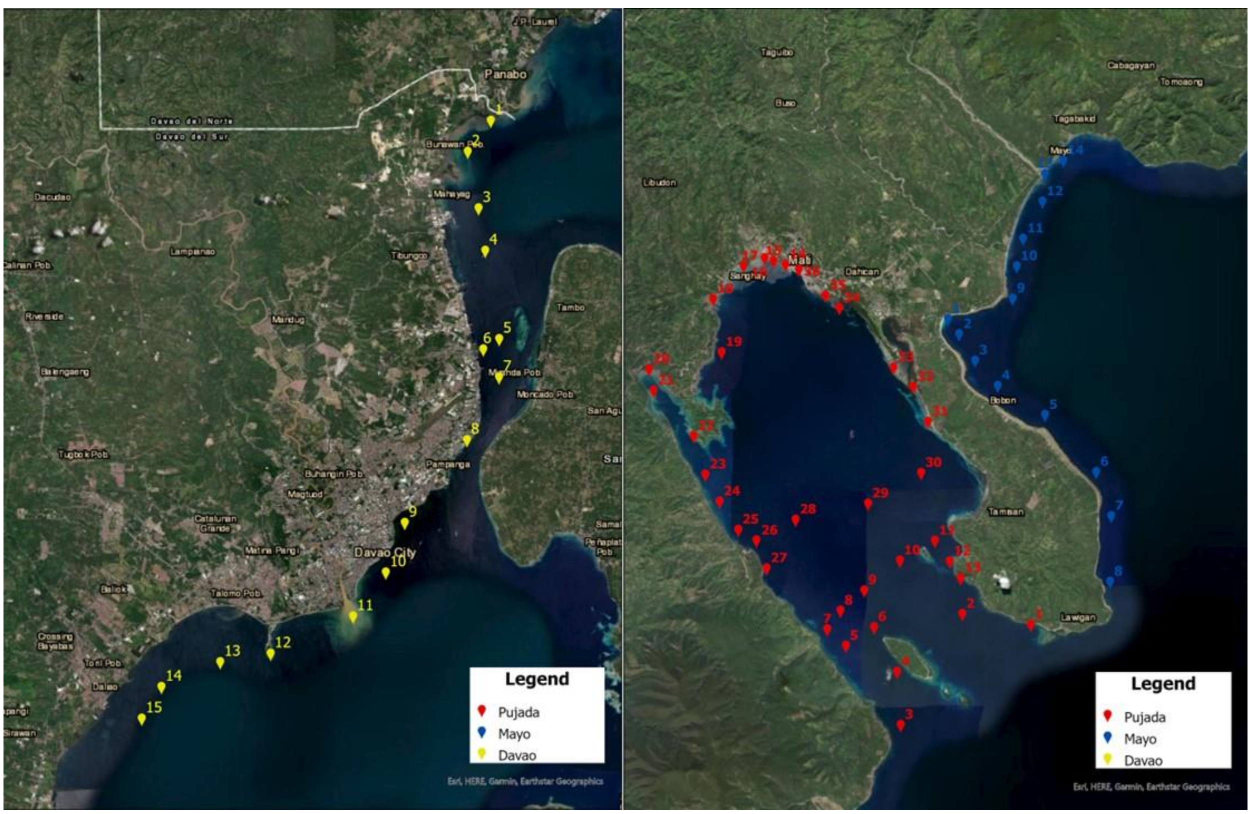

Figure 10. Survey area for water quality including the points samples.

Table 10. Water quality survey results.

Parameters	Pujada Bay	Mayo Bay	Mati		Davao	
			Sample	Score	Sample	Score
DO (7.0 - 8.0 mg/L)	8.39	8.7	8.5	0.88	9.3	0.66
TDS (< 30 mg/L)	26.09	26.12	26.1	1.00	25.60	1.00
Salinity (33 to 38 ppt)	34.24	34.26	34.25	1.00	33.50	1.00
Acidity (6.5 – 8.5 pH)	8.1	8.1	8.1	1.00	9.1	0.89
AVERAGE					0.97	0.89

4.4. Tourism and recreation criterion score

Tourism and recreation (TR) in coastal areas provide entertainment and relaxation for both locals and visitors, thereby significantly contributing to community income. In Davao City, three annual events stand out as major draws: Araw ng Davao in March, the Kadayawan Festival in August, and Pasko Fiesta sa Davao in December. Figure 11 provides visual documentation of these events. Similarly, Mati City has its own set of annual celebrations, such as Araw ng Davao Oriental in July, the Sambuokan Festival in October, and Summerfrolic in April, with images of these events shown in Figure 12. These events not only highlight the cultural richness of the respective cities but also contribute significantly to the local economy through tourism.

Figure 11. Tourism and recreation photos in Davao City.

Figure 12. Tourism and recreation photos of Mati City.

Tourist arrival data obtained from the Department of Tourism (DOT) offices in Davao City and Mati City, as well as the regional DOT office, provided valuable insights into tourist trends. Davao City divides tourists into three categories: domestic, foreign, and overseas Filipino workers (OFWs), whereas Mati City classifies tourists as domestic or foreign. The data for Davao City were collected from 2014 to 2023 (Table 12), while those for Mati city were collected from 2015 to 2023 (Table 13). Both cities experienced an increase in tourist arrivals from 2014 to 2019 before falling due to COVID-19-related lockdowns from the fourth quarter of 2019 to the first quarter of 2022. The recovery began in 2022, with tourist arrivals increasing and events resuming.

Given that the DOT does not provide detailed income data for each event, this study uses tourist arrival figures as a proxy to assess the health of both cities. Without established benchmarks for an acceptable number of tourists, we used a normalization technique for each type of tourist to calculate the average score for Davao and Mati. These average scores serve as a baseline for future evaluations. The tourism and recreation (TR) scores for Davao City and Mati city are 32.2% and 41.75%, respectively, indicating the importance of tourism to the overall health and economic vibrancy of these coastal towns.

Table 11. Davao City tourist arrival.

Tourist Type	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Domestic	1,411,342	1,586,688	1,716,224	1,838,311	2,150,185	2,345,168	580,442	295,796	850,440	1,210,140
Foreigners	111,553	128,622	124,863	126,294	184,484	482,825	30,326	8,120	41,067	72,849
OFW	7,012	14,699	23,256	48,020	58,715	45,697	7,266	13,888	5,899	13,939
TOTAL	**1,529,907**	**1,730,009**	**1,864,343**	**2,012,625**	**2,393,384**	**2,573,990**	**618,034**	**317,804**	**897,406**	**1,296,928**

Table 12. Mati City tourist arrival.

Tourist Type	2015	2016	2017	2018	2019	2020	2021	2022	2023
Domestic	31,977	1,157	2,999	4,098	7,694	742	217	826	488
Foreigners	9,769	146,742	289,712	283,908	203,244	30,326	369,008	385,344	316,807
TOTAL	**41,746**	**147,899**	**292,711**	**288,006**	**210,938**	**31,068**	**369,225**	**386,170**	**317,295**

4.5. Coastal livelihood criterion score

Coastal livelihood (CL) refers to activities related to coastal and marine environments that are important to communities. This study draws on data from the Philippine Statistics Authority (PSA) Region XI and city-specific offices to examine the scope of coastal livelihoods. According to the PSA survey, jobs in coastal livelihoods are classified as skilled agriculture, forestry, or fishery workers. This paper focused on the number of such workers in each city's coastal barangays (towns). Tables 14 and 15 systematically present the data for Mati City and Davao City, respectively. The methodology for calculating the health score involves dividing the total number of coastal workers by the total population of the coastal community. According to this calculation, the total coastal populations of Mati City and Davao City are 26,205 and 441,639, respectively, with 7,059 coastal workers in Mati City and 156,963 in Davao City. As a result, Mati and Davao City had calculated health scores of 26.94% and 35.54%, respectively. These scores provide a quantitative measure of the coastal livelihood sector's significance and health within the larger community structure, reflecting the proportion of the population involved in maintaining and using coastal and marine resources.

Table 13. Livelihood by coastal barangay in Mati City.

Barangays	Population	Skilled Agricultural, Forestry and Fishery Workers
Badas	2,549	573
Bobon	1,519	493
Cabuaya	616	290
Dahican	5,792	820
Dawan	1,442	606
Don Enrique Lopez	1,270	200
Langka	412	172
Lawigan	990	585
Luban	366	227
Macambol	1,403	796
Mamali	773	318
Matiao	5,634	557
Mayo	1,223	485
Tagabakid	584	182
Tagbinunga	535	279
Tamisan	1,097	476

Table 14. Livelihood by coastal barangay in Davao City.

Barangays	Population	Skilled Agricultural, Forestry and Fishery Workers
Alejandra	10,531	2,367
Binugao	7,679	2,492
Bucana	72,761	34,254
Bunawan	21,442	3,036
Centro	14,833	6,234
Daliao	19,410	3,057
Dumoy	17,692	7,386
Gov. Duterte	7,167	4,235
Ilang	23,322	14,465
Lapu-lapu	11,785	6,686
Leon Garcia Sr.	11,688	4,808
Lizada	21,073	2,083
Mahayag	6,292	2,495
Matina Aplaya	29,333	9,141
Monteverde Sr.	4,752	2,478
Pampanga	14,236	6,177
Panacan	35,932	9,679
Sasa	49,508	11,129
Sirawan	7,375	2,394
Tibungco	44,359	20,883
Vicente Hizon Sr.	10,469	1,482

4.6. Biodiversity and coastal protection score

Biodiversity (B) focuses on the protection status of marine-related species, highlighting the essential value of biodiversity. Due to the Department of Environment and Natural Resources (DENR) lack of specific species records for the two cities under study, this research emphasizes the significance of mangrove forests as indicators of biodiversity abundance and protection within coastal communities, alongside other crucial species in the area.

Figure 13 depicts the likelihood of mangrove survival in various locations using a color scale in which blue indicates a very low to zero probability of mangrove presence, and the spectrum from green to red represents a greater likelihood of survival, ranging from 50% to 100%. The white box indicates the sample location for the mangrove study, confirming the model's reliability and high accuracy, as evidenced by training and testing area under the curve (AUC) values of 98.5% and 97.9%, respectively.

Figure 14 shows that the analysis revealed that the environmental factors significantly influenced the mangrove potential locations. Elevation emerges as the dominant factor, where approximately 58% of the model's predictive capacity is attributed to areas with elevations less than 15 meters, indicating that these zones are highly viable for mangrove sustainability. With elevation, temperature plays a crucial role, with optimal mangrove growth identified in regions where temperatures range between 28 and 30 degrees Celsius, accounting for 28% of the model's considerations. The normalized difference vegetation index (NDVI) is also highlighted, where mangrove reflectance values between 0.2 and 0.5 further inform the model's predictions. Other factors are determined to have less significant impacts on mangrove spatial prediction and distribution, such as elevation, temperature, and NDVI, which are the primary environmental factors influencing mangrove survival and distribution.

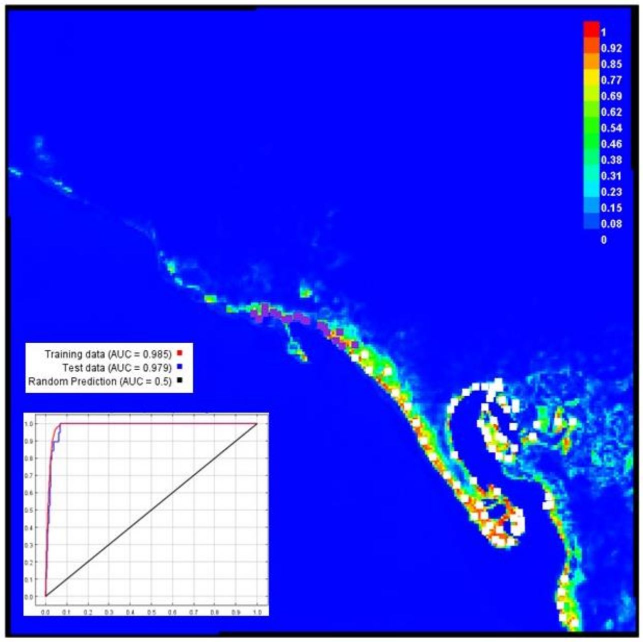

Figure 13. Biodiversity results.

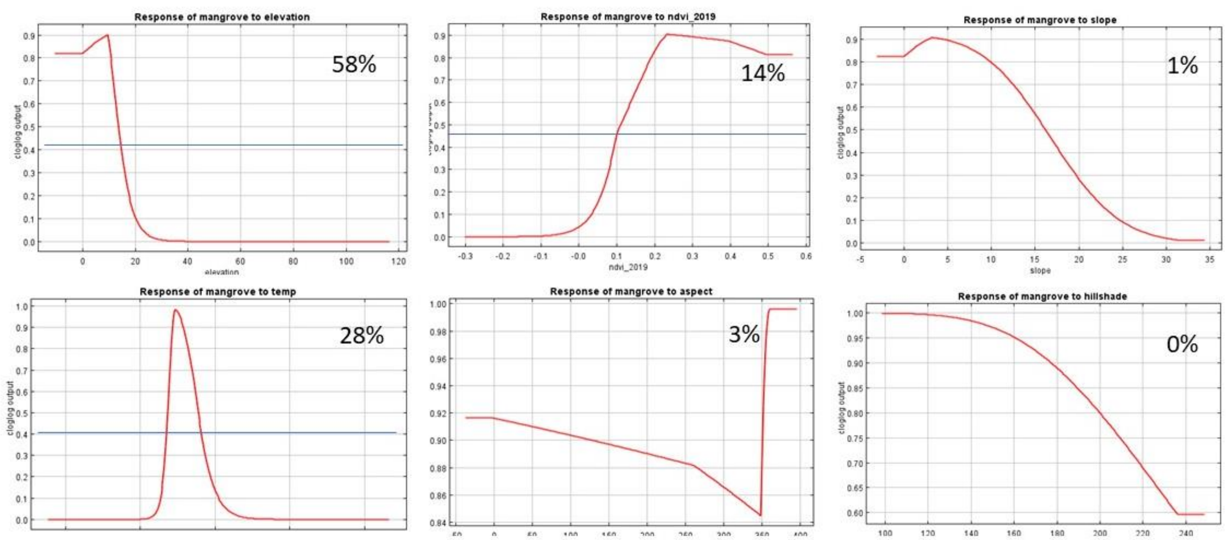

Figure 14. Biodiversity criteria contribution.

Figure 15 and Figure 16 show the mangrove distributions in Mati city and Davao City for 2013 and 2023, respectively. The shoreline is shown in blue. The white color is the shoreline's 200 m seaward and landward buffer zone. The red color inside the buffer zone is the 80 to 100% spatial distribution of mangroves according to the maximum modeling results. For Mati city, the spatial coverage of mangroves in 2013 was 197.8 km^2 or 20.12% of the total area of the coastal area, while it was 120.7 km^2 or 13.24% for 2023. There has been a significant reduction in the spatial coverage of mangroves over the decade. In 2013, mangroves covered 197.8 km², representing 20.12% of the coastal area. The analysis of mangrove coverage changes in Mati city from 2013 to 2023 revealed significant environmental alterations over the studied decade. A detailed examination revealed an absolute decrease in the mangrove area of approximately 77.1 km². When expressed as a percentage, this decrease amounts to a substantial 38.98% reduction compared to the mangrove coverage in 2013. This marked decline underscores the pressing environmental concerns facing the coastal ecosystems of Mati city. The primary reason for the decrease in mangrove area is the conversion of mangrove lands into shrimp ponds. This conversion was particularly notable during the COVID-19 pandemic lockdown from 2019 to early 2022, when it was easier for fishpond owners to expand without attracting the attention of the Department of Environment and Natural Resources (DENR). Additionally, local communities have been using mangrove wood for charcoal production as an alternative source of income. On the other hand, in Davao City, the spatial coverage of mangroves in 2013 was 23.9 km^2 or 9.3% of the total area of the coastal area, while it was 17.3 km^2 or 7.2% for 2023. There was a slight reduction in the spatial coverage of mangroves over the decade.

Figure 15. Mangrove distribution in Mati City: 2013 (left) and 2023 (right)

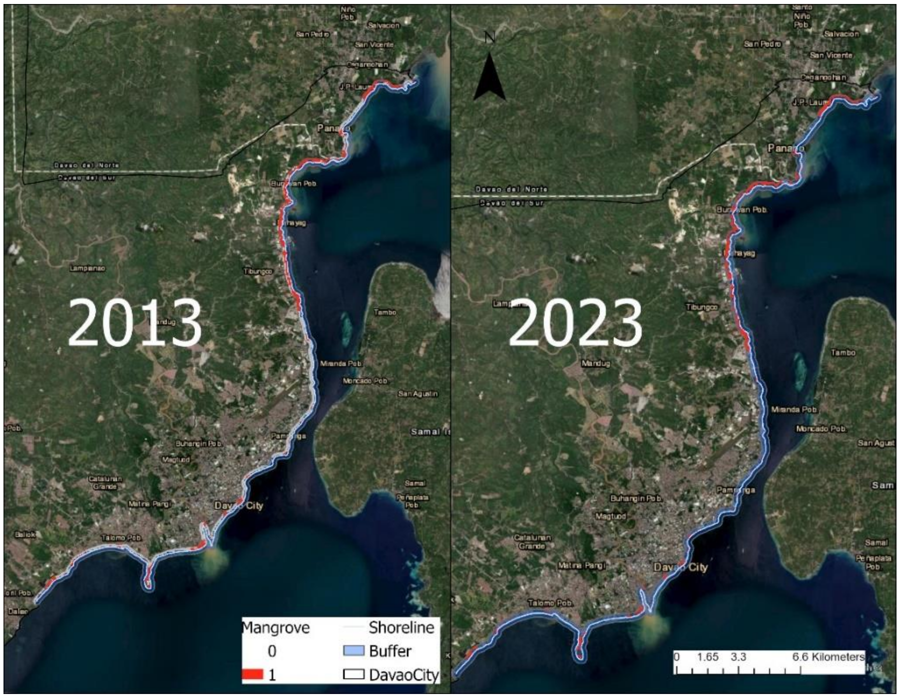

Figure 16. Mangrove distribution in Davao City: left (2013) and right (2023)

4.7. Carbon storage criterion score

Carbon storage is crucial for mitigating climate change by capturing and storing atmospheric carbon dioxide (CO2). Recent research underscores the role of mangroves in carbon sequestration. This study highlights their multifaceted benefits, including climate change mitigation, fisheries enhancement, coastal erosion protection, and support for local economies through tourism. In this study, mangrove forests were used to calculate carbon sequestration for 2013 and 2023, as shown in Figure 17 (Mati city) and Figure 26 (Davao City).

According to the literature, a hectare of mangrove forest can absorb approximately 33.6 metric tonnes of CO2 annually. Given the total land area for mangroves in hectares (which is the area in km^2 multiplied by 100, as there are 100 hectares in 1 km^2), we calculate the annual CO2 sequestration for each year. The land areas of mangroves in Mati city were 197.8 km2 (19780 hectares) and 120.7 km2 (12070 hectares) for 2013 and 2023, respectively, while the land areas of mangroves in Davao City were 23.9 km^2 (2390 hectares) and 17.3 km2 (1730), respectively, as discussed in the previous section. Therefore, the carbon sequestration amounts for Mati city are approximately 664,608 (2013) and 405,552 (2023) metric tonnes, while the carbon sequestration amounts for Davao City are approximately 80,304 (2013) and 58,128 (2023) metric tonnes.

To establish the health score, 2023 carbon sequestration points were considered as the baseline or 100% reference points. Then, let us compute the percentage change in 2023 relative to the 2013 baseline information. In this case, the score ranges from 0 to 100, with 100 representing no decrease and 0 indicating a complete loss of mangrove carbon sequestration capacity. The score for 2023 is the remaining percentage of the 2013 carbon sequestration level according to the following equation: Score = $[1 - (CO_2\ seq_{2013} - CO_2seq_{2023})/CO_2seq_{2013}]*100$. Therefore, the scores are approximately 61.02% and 72.38% for Mati and Davao City, respectively.

4.8. Sense of place criterion score

The sense of place concept is the interaction between people and places (Wang et al., 2024), and the literature defines a sense of place as the significance of place to the emotional value of a person (Abou-Shouk et al., 2018; Wang et al., 2024). It is also defined as a complex emotional bond between people and a place. Sense of place has been categorized into place attachment, local attachment, place identity, and place dependence (Pretty et al., 2003; Shaykh-Baygloo, 2021).

Tables 16 and 17 show the sample sizes per barangay for Mati and Davao City, respectively. There are 150 intended respondents in each city. The sample size per barangay is equal to the product of 150 multiplied by the result of the division of the barangay population divided by the total population of the city. On the other hand, the spot number is randomly generated from the five sample points. These are (1) the barangay captain's house, (2) the house of worship, (3) the barangay hall, (4) the health center, and (5) the school. The next respondent is a household member of the next house. The respondents were 18 years old or older. Each questionnaire has a unique number to ensure easy validation for possible errors in the survey.

Table 15. Coastal barangay population in Mati City.

Barangays	Population	Sample Size	Question No.	Spot No.
Badas	2,549	15	1-15	3
Bobon	1,519	9	16-24	1
Cabuaya	616	4	25-28	1
Dahican	5,792	33	29-61	1
Dawan	1,442	8	62-70	4
Don Enrique Lopez	1,270	7	71-77	1
Langka	412	2	78-79	3
Lawigan	990	6	80-85	5
Luban	366	2	86-87	2
Macambol	1,403	8	88-95	5
Mamali	773	4	96-99	2
Matiao	5,634	32	100-131	5
Mayo	1,223	7	132-138	3
Tagabakid	584	3	139-141	1
Tagbinunga	535	3	142-144	2
Tamisan	1,097	6	145-150	5
TOTAL	26,205	150	-	-

Table 16. Coastal barangay population in Davao City.

Barangays	Population	Respondents	Question No.	Spot No.
Alejandra	10,531	4	1-4	5
Binugao	7,679	3	5-7	4
Bucana	72,761	25	8-31	4
Bunawan	21,442	7	32-39	5
Centro	14,833	5	40-44	1
Daliao	19,410	7	45-50	5
Dumoy	17,692	6	51-56	3
Gov. Duterte	7,167	2	57-59	4
Ilang	23,322	8	60-67	2
Lapu-lapu	11,785	4	68-71	1
Leon Garcia Sr.	11,688	4	72-75	4
Lizada	21,073	7	76-82	4
Mahayag	6,292	2	83-84	3
Matina Aplaya	29,333	10	85-94	3
Monteverde Sr.	4,752	2	95-96	1
Pampanga	14,236	5	97-101	4
Panacan	35,932	12	102-113	3
Sasa	49,508	17	114-130	3
Sirawan	7,375	3	131-133	4
Tibungco	44,359	15	134-146	2
Vicente Hizon Sr.	10,469	4	147-150	4
TOTAL	441,639	150	-	-

From May 26 to June 13, 2024, a survey was conducted in the City of Mati and Davao. An on-site questionnaire survey was carried out using mobile phones. Before starting the questionnaires, the surveyor explained the purpose of the survey and confirmed that the respondents were willing to participate. Residents and tourist respondents were also informed that the survey would be used for academic research purposes and that their identities would not be disclosed.

The reliability of the questionnaire was tested using confirmatory factor analysis. The Cronbach's α and Guttman's $\lambda 6$ for Davao City residents are 0.847 and 0.866, respectively. For the tourists in Davao City, the Cronbach's α and Guttman's $\lambda 6$ were 0.905 and 0.931, respectively. Moreover, for the residents and tourists of Mati city, the Cronbach's α values are 0.913 and 0.896, respectively, and the Guttman's $\lambda 6$ values are 0.936 and 0.924, respectively (see Tables 18 & 19). These results indicate high internal consistency of the scale, suggesting that removing any single item does not significantly decrease overall reliability. Therefore, we concluded that the measurement model had sufficient reliability and validity.

The model fit indices met the acceptability criteria as follows: the χ^2/df was equal to or less than 3, and the CFI, TLI, and GFI were above 0.80, as shown in Table 17.

Table 17. Model fit indices results.

Model	**n**	**χ^2**	**df**	**χ^2/df**	**CFI**	**T-size CFI**	**TLI**	**GLI**
Davao Resident	150	77.24	33	2.34	0.981	0.962	0.968	0.984
Davao Tourist	150	74.86	68	1.10	0.999	0.997	0.999	0.995
Mati Resident	150	102.2	33	3.09	0.987	0.980	0.978	0.995
Mati Tourist	150	186.8	68	2.75	0.985	0.978	0.977	0.983

Table 18. Results of the confirmatory factor analysis for resident respondents

Latent	Item	Standardized Loading		Guttman's λ6		Cronbach's α	
		Davao	Mati	Davao	Mati	Davao	Mati
Identity and Place	IP1	0.796	0.873	0.853	0.926	0.835	0.904
Memories and Experiences	ME1	0.943	0.987	0.853	0.926	0.833	0.904
Perceptions of Physical Attributes	PP1	0.574	0.806	0.853	0.930	0.834	0.907
Community Involvement	CI1	0.660	0.862	0.851	0.930	0.832	0.907
	CI2	0.514	0.685	0.854	0.930	0.834	0.909
Protection	P1	0.506	0.744	0.860	0.926	0.839	0.905
	P2	0.691	0.747	0.848	0.925	0.838	0.905
Future Aspirations	FA1	0.748	0.701	0.844	0.923	0.827	0.899
	FA2	0.637	0.858	0.859	0.931	0.840	0.907
Sense of Place	SOP1	0.654	0.871	0.856	0.928	0.839	0.906
	SOP2	0.599	0.750	0.855	0.931	0.840	0.909
	SOP3	0.796	0.873	0.853	0.933	0.836	0.913

Table 19. Tourist respondent results of the confirmatory factor analysis.

Latent	Item	Standardized Loading		Guttman's λ6		Cronbach's α	
		Davao	Mati	Davao	Mati	Davao	Mati
Cultural Engagement	CE1	0.944	0.854	0.923	0.917	0.895	0.889
	CE2	0.940	0.969	0.922	0.922	0.893	0.896
Comparisons to Home	CH1	1.342	0.872	0.923	0.915	0.894	0.886
	CH2	0.189	0.544	0.920	0.916	0.892	0.885
Environmental Perception	EP1	0.835	0.882	0.918	0.913	0.891	0.883
	EP2	0.893	0.796	0.918	0.910	0.891	0.879
Future Intentions	FI1	0.887	0.770	0.924	0.914	0.900	0.888
	FI2	0.837	1.010	0.921	0.920	0.897	0.891
Impressions	I1	0.847	0.956	0.924	0.913	0.899	0.884
	I2	0.868	0.631	0.924	0.913	0.896	0.883
Memorable Experiences	ME1	0.229	0.454	0.927	0.914	0.902	0.883
Social Interactions	SI1	0.798	0.923	0.938	0.920	0.928	0.904
	SI2	0.834	0.930	0.924	0.920	0.896	0.891
Sense of Place	SOP1	0.819	0.749	0.923	0.917	0.895	0.889
	SOP2	0.840	0.728	0.922	0.922	0.893	0.896

Tables 20 and 21 depict the regression coefficients and factor covariance results, respectively. Figures 17 and 18 show the results of the hypothesis path test for the residents of Davao City. FA did not have a significant influence on SOP, with regression coefficients of 0.0404 for Davao and 0.158 for Mati. Similarly, CI did not significantly influence SOP, with coefficients of 0.076 and 0.254 for Davao and Mati, respectively. However, the ME of Mati residents positively influenced the SOP, and the IP of Davao residents had a potentially significant influence on the SOP. Overall, the SOP had a greater positive effect on the protection of the coastal zone environment.

For the tourist respondents, I had a positive effect on SOP in Davao, with a coefficient of 0.918. In Mati city, I, EP, and SI positively affected the SOP, with coefficient values of 0.729, 0.841, and 0.586, respectively. Conversely, CHs and MEs negatively affected SOP in Mati city. Overall, SOP positively influenced the FI of tourists in both Mati and Davao.

According to the covariance analysis for the residents (Table 21), ME and FA had positive influences on IP (0.701 and 0.513, respectively), leading to a positive influence on SOP. Among Davao residents, there was a positive correlation between IP and ME, although not enough to impact SOP. The covariance analysis for tourists is shown in Table 21. In Davao City, CD, SI, and ME had indirect effects on SOP since these latent variables were highly correlated with impressions. Moreover, in Mati city, SI and CH had indirect effects on SOP via I, while CE also had an indirect effect on SOP via SI. Notably, the memories and experiences of the residents of Mati city had the most positive effect on sense of place, leading to the protection of the environment. On the other hand, as for tourists, impressions positively affected the sense of place in both cities, leading to future intentions to return or recommend visiting the city.

The correlations of the SOP with protection are 0.884 and 0.827 for Davao and Mati residents, respectively. For tourists, the correlations of SOP with future intentions are 0.875 and 0.768 for Davao and Mati, respectively. The Sense of Place scores for Davao City and Mati City is the average correlation results. Therefore, the score for Mati is 0.7975, and that for Davao City is 0.8795.

This study provides essential insights for tourism and environmental awareness. First, by exploring tourists' sense of place, this research provides a meaningful understanding of the emotional connections between tuorists/residents and tourist sites, including cultural and environmental heritage sites. This helps to raise public awareness and encourages society to better understand the emotional bonds that exist between tourists, locals, and these unique places and tourist destinations. Second, the study demonstrates that residents' sense of place plays a positive role in the preservation of sites, highlighting the importance of tourism destinations in society.

Furthermore, this contributes to raising societal awareness of site conservation, fostering a sense of responsibility in people to actively participate in protecting these places.

Table 20. Regression coefficient results for the two cities.

Predictor	Outcome	Resident		Tourist	
		Davao	Mati	Davao	Mati
Sense of Place (SP)	Protection	0.884	0.827	-	-
Identity and Place (IP)	Sense of Place	0.422	0.181	-	-
Memories and Experiences (ME)	Sense of Place	0.377	0.539	-	-
Community Involvement (CI)	Sense of Place	-0.076	0.254	-	-
Future Aspirations (FA)	Sense of Place	0.404	0.158	-	-
Sense of Place (SOP)	Future Intentions	-	-	0.875	0.768
Impressions (I)	Sense of Place	-	-	0.918	0.729
Environmental Perception (EP)	Sense of Place	-	-	0.343	0.841
Cultural Engagement (CE)	Sense of Place	-	-	0.194	-0.080
Social Interactions (SI)	Sense of Place	-	-	-0.285	0.586
Comparisons to Home (CH)	Sense of Place	-	-	0.043	-0.541
Memorable Experiences (ME)	Sense of Place	-	-	-0.195	-0.649

Table 21. Factor covariance results for the two cities.

Variables	Resident		Tourist	
	Davao	Mati	Davao	Mati
Identity and Place - Memories and Experiences	0.575	0.701	-	-
Identity and Place - Community Involvement	0.338	0.483	-	-
Identity and Place - Future Aspirations	0.269	0.513	-	-
Memories and Experiences - Community Involvement	0.38	0.473	-	-
Memories and Experiences - Future Aspirations	0.35	0.485	-	-
Impressions - Emotional Response	-	-	0.471	0.392
Impressions – Cultural Engagement	-	-	0.68	0.472
Impressions – Social Interactions	-	-	0.618	0.538
Impressions – Comparisons to Home	-	-	0.478	0.608
Impressions – Memorable Experiences	-	-	0.561	0.449
Cultural Engagement - Social Interactions	-	-	0.608	0.574
Cultural Engagement - Comparisons to Home	-	-	0.437	0.632

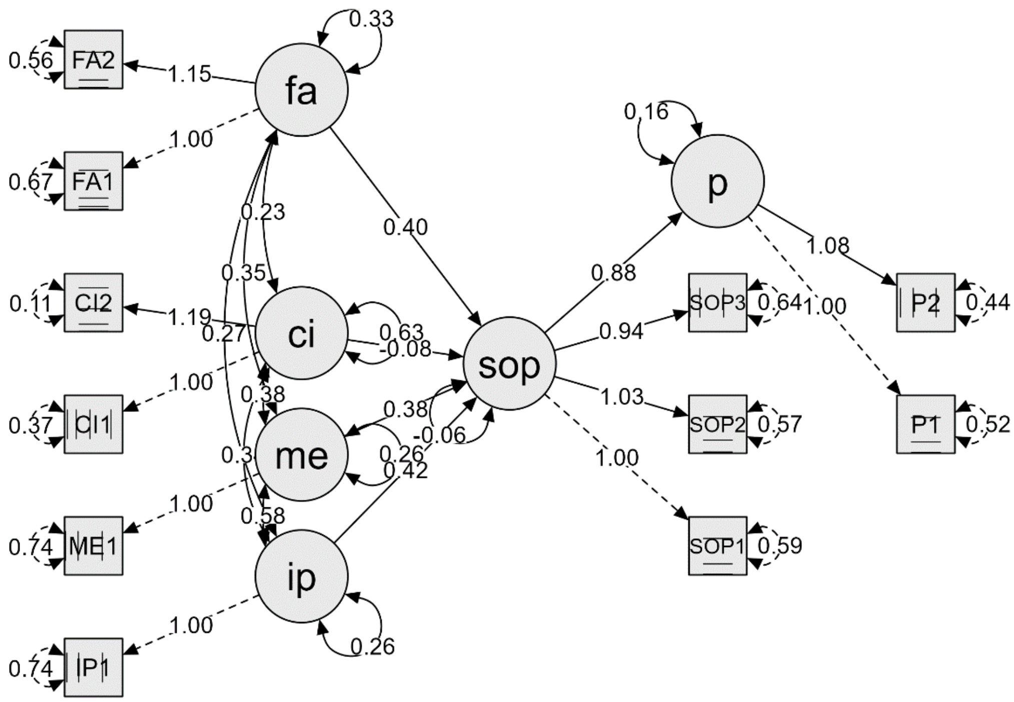

Figure 17. Sense of Place SEM for the residents of Davao City.

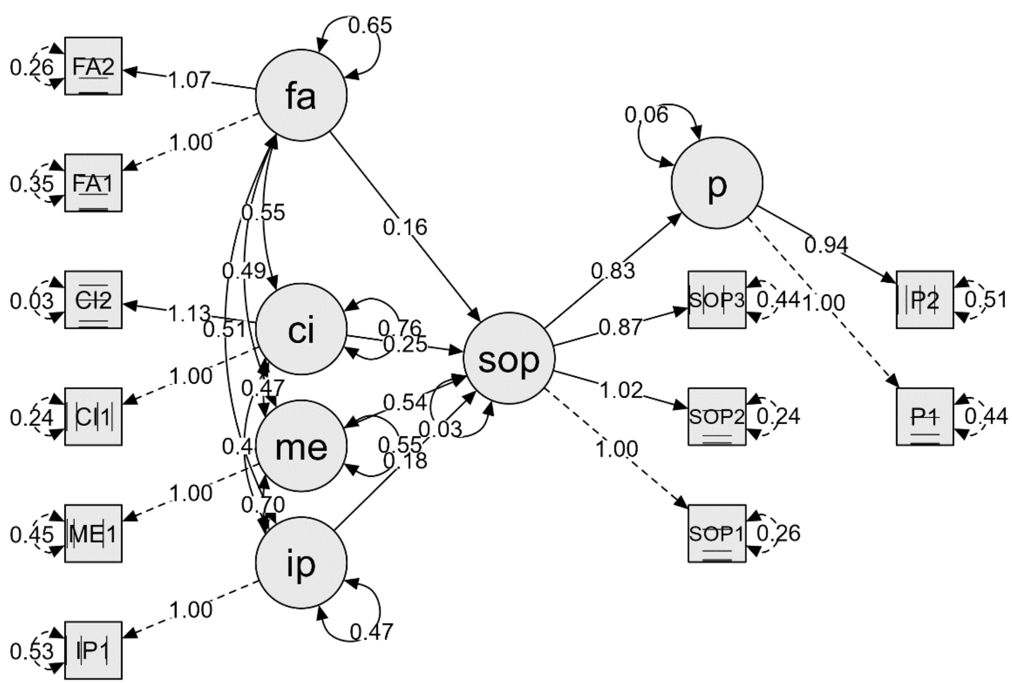

Figure 18. Sense of Place SEM for the residents of Mati City.

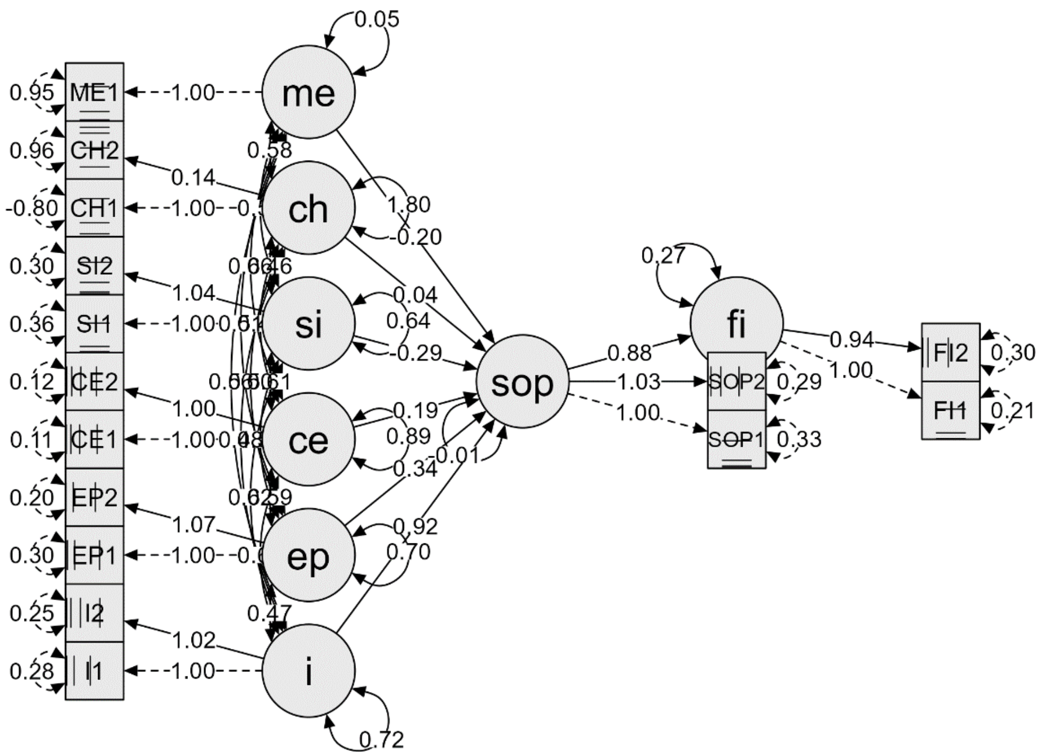

Figure 19. Sense of Place SEM for the tourists of Davao City.

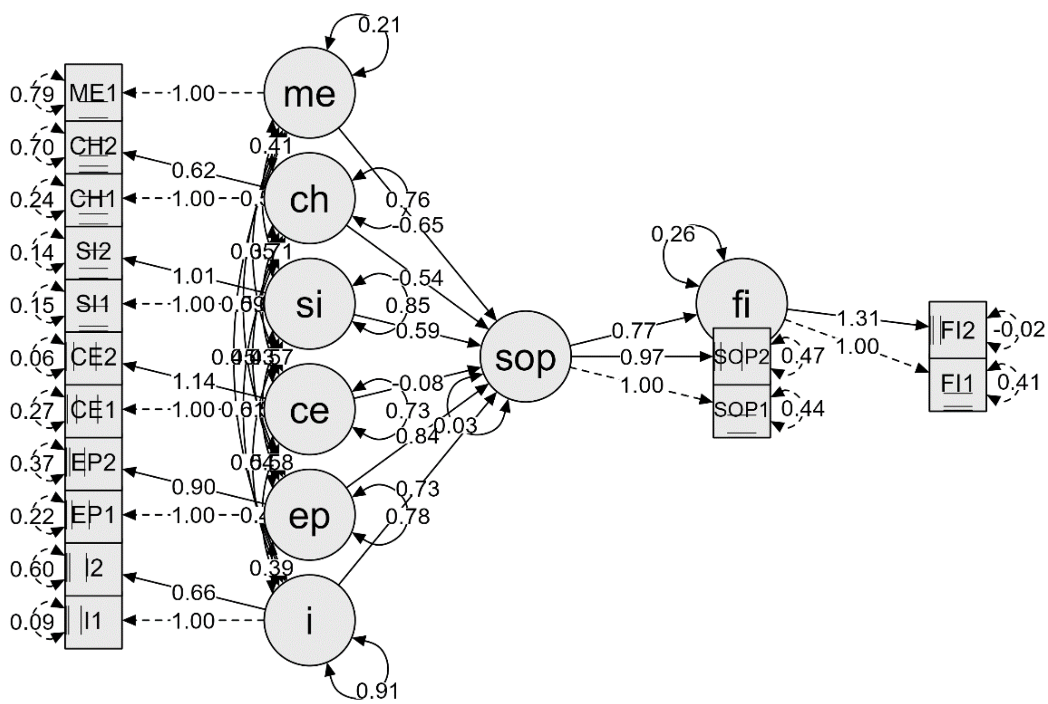

Figure 20. Sense of Place SEM for the tourists of Mati City.

4.9. Natural products criterion score

This study focused on naturally sourced marine products, encompassing diverse items derived from marine environments with minimal human alteration. These include seafood (such as fish, shellfish, and seaweed), food and supplemental ingredients (such as fish oil, sea salt, and blue algae), cosmetic and pharmaceutical compounds (such as marine collagen and seaweed extracts), pearls, and energy sources from marine biomass.

To evaluate the health scores of the two cities, secondary data from the Bureau of Fisheries and Aquatic Resources (BFAR) were used. These data explicitly provide fish yields from 2020 to 2023 (referenced in Table 10, subsection 4.2). Consequently, the health score derived for naturally produced sea products aligns with that of the fisheries sector, recorded at 56.88% for Mati City and 33.44% for Davao City.

Chapter 5 - Coastal Zone Vulnerability Assessment

The current study will employ an index-based methodology, specifically the coastal vulnerability assessment (CVA) (Hastuti et al., 2022). The data were gathered from various sources to create an initial parameter database. Table 3 details the parameters used in this assessment. The parameter was qualitatively ranked based on the relative resistance of a given land formation to erosion, whereas the data values were assigned a vulnerability ranking based on value ranges contributing to coastal vulnerability. Each parameter input is assigned an appropriate risk level based on its potential to cause very low, low, moderate, high, and very high damage to a specific area of the coastline (Table 4). The significant factors are combined into a single index using Equation 6 and classified based on their relative values.

5.1. Geomorphological assessment

Figure 21 shows the geomorphology of Davao and Mati city. The coastal areas of Davao City have a geomorphic classification of one, accounting for approximately 45% of the total records. Classification 1 denotes rocky, cliff-side, and man-made structures. This is because the city is currently constructing coastal roads and seawalls. In addition, approximately 30% of coastal areas are classified as type 5: sand beach, salt marsh, mudflats, and deltas. Mati city, on the other hand, is a predominantly low cliff and plain, approximately 45%, followed by 23% and 22% of class 4 (i.e., cobble beach, estuary, and lagoon) and 5 (i.e., sand beach, saltmarsh, mudflat, and coral areas), respectively.

Figure 21. Geomorphology assessment of Davao (left) and Mati City (right).

5.2. Elevation assessment

Figure 22 depicts the coastal elevations of both cities. Low-elevation coastlines are more vulnerable to coastal flooding and erosion and may sustain more damage as a result of these events. At the same time, plants at higher elevations are thought to be more resistant to such impacts. Furthermore, it is less likely to be inundated as sea levels rise. One-third (33%) of Davao City's areas are slightly elevated, ranging from 5 to 20 meters. Unfortunately, 66% are classified as 5, which means they have an elevation of less than 5 meters. These regions are susceptible to SLR, storm surges, and other coastal hazards.

The majority of the coastal areas of Mati city are between 5 and 10 meters in elevation, accounting for approximately 48%, with 41% of coastal elevations falling between 5 and 10 meters. Only a small percentage of the area (7%) is extremely close to sea level. Additionally, a minor segment (4%) falls under the second classification, which ranges from 20 to 30 meters. These are low cliff areas at the foot of Mt. Hamiguitan.

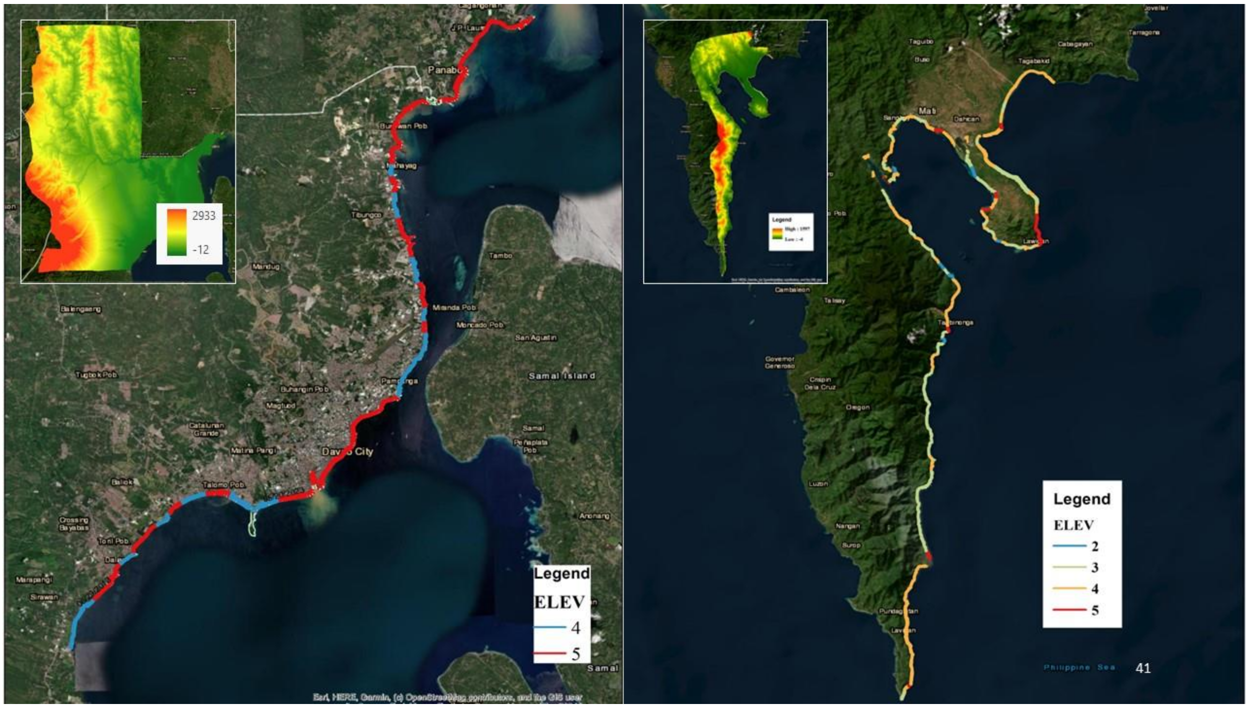

Figure 22. Elevation assessment of Davao (left) and Mati City (right).

5.3. Sea surface temperature assessment

Figure 23 depicts the sea surface temperatures for the two study cities. Sea surface temperature is an important factor to consider in coastal vulnerability assessments because it has a significant impact on physical and biological processes in the coastal environment. Furthermore, variations in sea surface temperature can have an impact on the distribution and abundance of marine species, as well as the health of coral reefs and other coastal habitats. Furthermore, it has the potential to influence the intensity and frequency of storms and other extreme weather events, which can have both direct and indirect effects on the shoreline and coastal communities. The SSTs in Davao and Mati city have been consistently classified as Class 3 for the past ten years, indicating a temperature range of 29-30°C. This indicates that the observed SSTs for all the locations in the coastal zone fall within the 29-30°C range. Such consistently warm sea surface temperatures can have implications for various marine and coastal processes, including coral reef health, evaporation rates, and potential influences on local weather patterns.

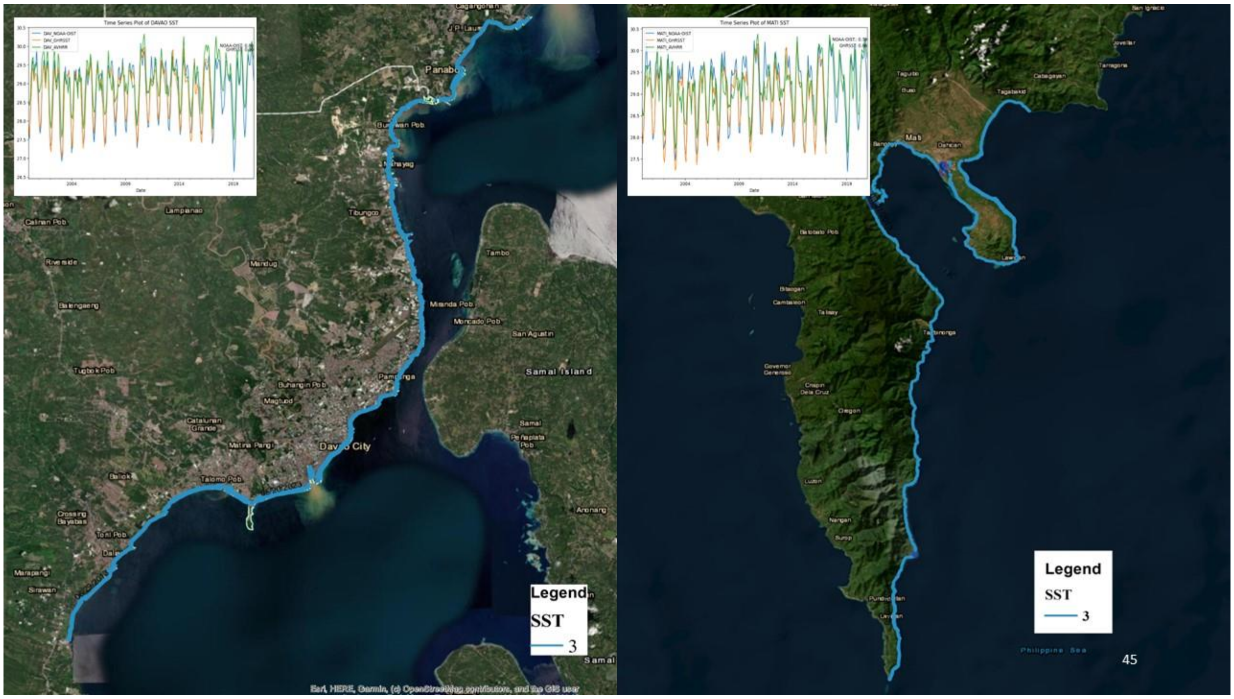

Figure 23. Sea surface temperature assessment of Davao (left) and Mati City (right).

5.4. Wave assessment

Figure 24 describes the wave assessment of Davao and Mati city. This paper utilized the significant wave height (SWH) from ERA5. The SWH is the average height (trough to crest) of the highest one-third of waves within 12 h. As wave energy increases, the mobilization and transport of coastal material also increase. Coastal areas with higher significant wave heights are considered more vulnerable than coastal areas with lower significant wave heights (Hastuti et al., 2022).

The dataset consistently measures the SWH for Davao City's coastline, with all values falling under SWH Class 1 (0.39 m). This uniform classification spans the 77 km coastline, indicating a consistent wave height measure across the city's coastal areas. In the coastal zone of Mati city, the SWH data reveal a varied distribution of wave conditions. Most of the observations, approximately 39.21%, experienced wave heights within the range of 0.85 to 1.05 meters. Approximately 38.30% of the areas encounter waves falling within the 0.55 to 0.85 m range. A smaller fraction of the dataset, approximately 22.49%, shows more calm conditions with wave heights below 0.55 meters. This distribution indicates that during the observed period, most parts of Mati city's coastal region experienced moderate wave heights, ranging between 0.55 and 1.05 meters.

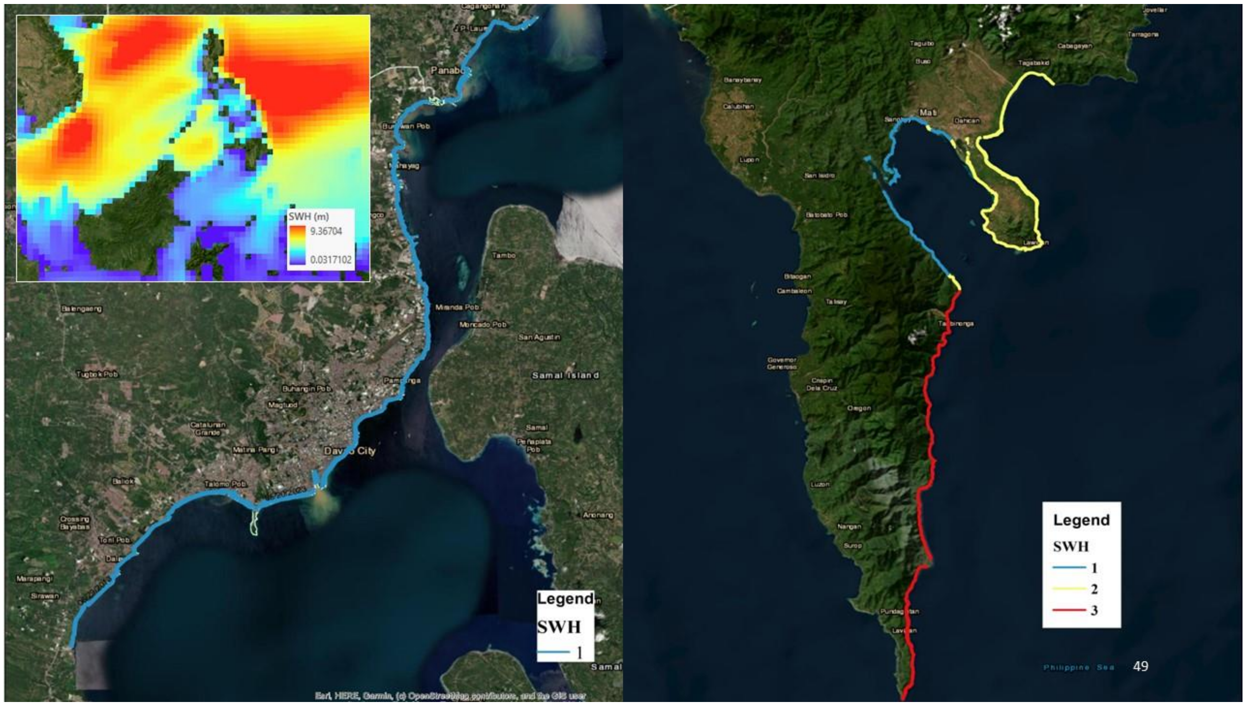

Figure 24. Significant wave height assessment of Davao (left) and Mati City (right).

5.5. Shoreline change rate assessment

Figure 25 and Table 23 show the shoreline change rates in the two cities. Figure 25 displays the spatial distribution, while Table 23 depicts the percentage contribution according to the classes. Classification 4, which is a negative accretion ranging from -1.1 to -2.0, is the significant portion of the coastline in Davao City at 42.76 km (55.54%), followed by the 3rd class (i.e., -1 to 1), with approximately 19% of the coastline. Areas in the 4th class indicate a very dynamic shoreline. Given their extensive stretch and high rate of change, these regions demand urgent and continuous monitoring coupled with proactive interventions. These areas may require mitigation strategies or reinforcements to manage the changing shoreline effectively. Overall, the SCR classification clearly revealed the dynamic coastline of Davao City. With over half of the coastline (SCR Class 4) undergoing significant changes, there is an urgent need for comprehensive monitoring and proactive interventions.

In Mati city, the 2nd class was the most prominent, representing approximately 50.32% of the coastline. This translates to an estimated length of 95.11 km, followed by the 3rd, 4th, 1st, and 5th classes with lengths of approximately 19% (36.28 km), 14 (23.23 km), 11% (20.59 km), and

6% (10.79 km), respectively. The entire coastline of Mati city spans 189 km, which is at least low in terms of the changes in the shoreline due to the geomorphic types of the coastal areas.

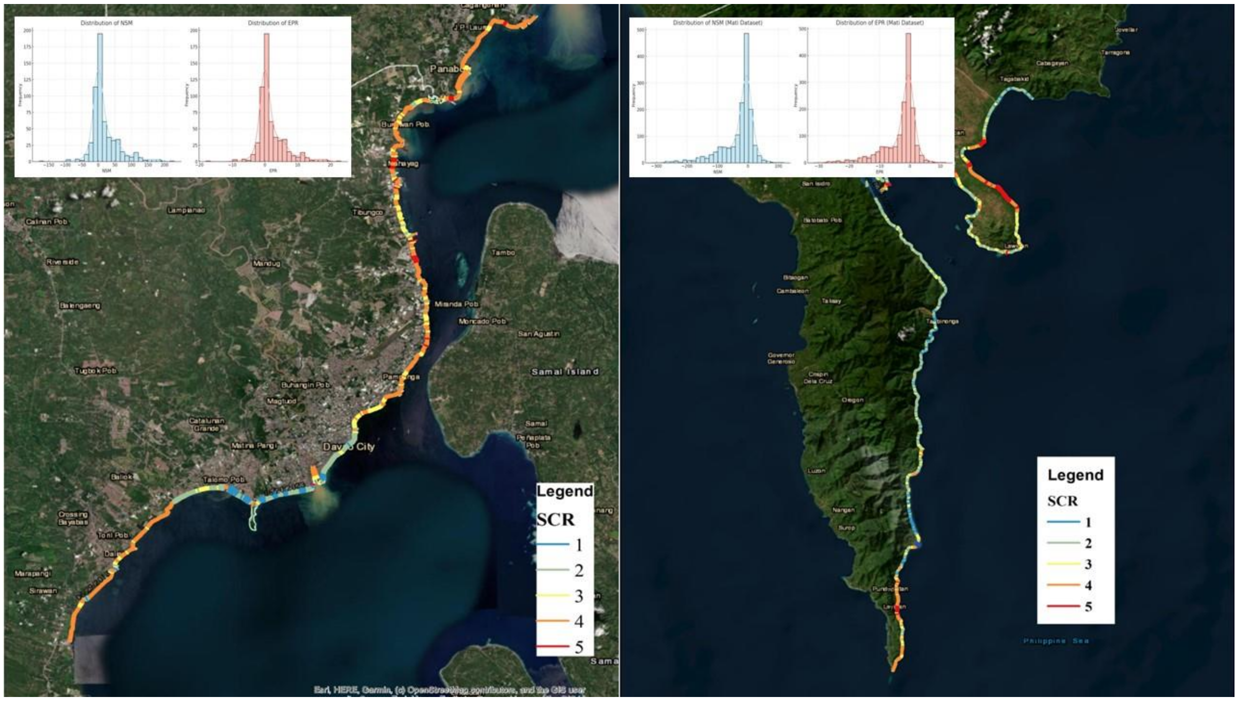

Figure 25. Shoreline coastal rate assessment for Davao City (left), and Mati City (right).

Table 22. Shoreline change rate for the two cities.

Class	Length (km)		Percentage (%)	
	Davao	Mati	Davao	Mati
1 (>= 2.1)	4.98	20.59	6.47	10.89
2 (1 to 2)	11.81	95.11	15.33	50.32
3 (-1 to 1)	14.69	36.28	19.08	19.20
4 (-1.1. to -2.0)	42.76	26.23	55.54	13.88
5 (<= -2.0)	3.58	10.79	2.75	5.71

5.6. Sea level change rate assessment

Table 24 shows the locations of all available tide gauges in the Philippines. There are 28 stations in the Philippines and one station each in the study area (Davao and Mati City). The sea level rate of the Philippines has reached approximately 4.9 ± 2.27 mm/year over the last two decades. Even though this increase is high compared to the global sea level rise, which is 3.5 ± 0.36 mm/year (Cabrera et al. (2024), unpublished), there is a variation in the rate of sea level due to the archipelagic nature of the Philippines. Figures 26 and 27 show the results of the ICEEMDAN model for Davao City and Mati City. In the first decade (i.e., 2000-2010), the trend of sea level rise in Davao City was fortunate; in 2011, the SLR decreased, but it gradually returned to an increasing trend. The sea level rate in Davao City is 0.8 ± 0.02 mm/year. The risk classification of Davao City is 1. Mati City has a severe increasing trend at approximately 1.4 ± 0.02 mm/year with a risk classification of 5. This is due to the location of the city facing the Pacific Ocean. Additionally, the rate was triggered by several earthquakes that occurred in this city. Recent large earthquakes of magnitude 6.1 occurred on March 2024, and multiple severe earthquakes occurred in recent decades. Furthermore, this city is connected to the Philippine faultline from Luzon Island down to Mindanao to Mati City.

Table 23. Tide gauges stations in the Philippines.

Location	Station ID	Latitude	Longitude
San Fernando, La Union	548	16.617	120.3
San Jose	1711	12.333	121.083
Port Irene	1705	18.383	122.1
Caticlan Malay, Aklan	2172	11.95	121.933
Pulupandan, Negros Occidental	2151	10.517	122.8
Currimao, Ilocos Norte	2173	17.983	120.483
Balanacan, Marinduque	2157	13.533	121.867
Subic, Zambales	2176	14.767	120.25
S. Harbor, Manila	145	14.583	120.967
Legaspi, Albay	522	13.15	123.75
Virac, Catanduanes	2150	13.583	124.233
Real Quezon	2035	14.667	121.6
Tacloban, leyte	664	11.25	125
Cebu	394	10.3	123.917
Balintang, Quezon, Palawan	2155	9.35	118.133
Puerto Princesa, palawan	207	9.75	118.733
Mati, Davao Oriental	2156	6.95	126.217
Davao, Davao City	537	7.083	125.633
Pagadian City	2152	7.817	123.433
Makar, General Santos City	2153	6.1	125.15
Zamboanga City	2175	6.917	122.067
Jolo, Sulu	260	6.067	121
Macabalan Port, Cagayan de Oro	2154	8.5	124.667
Tandag, Surigao del Sur	2158	9.083	126.2
Mambajao, Camiguin	2174	9.25	124.733
Surigao	1708	9.783	125.5

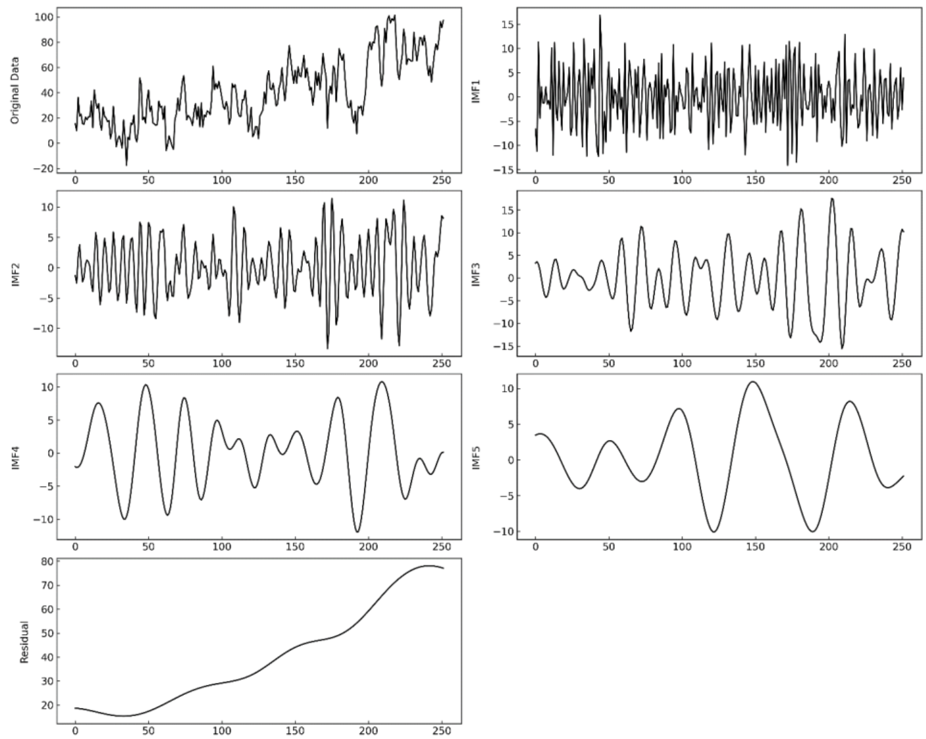

Figure 26. Davao City MSL fluctuation with the trend obtained using ICEEMDAN

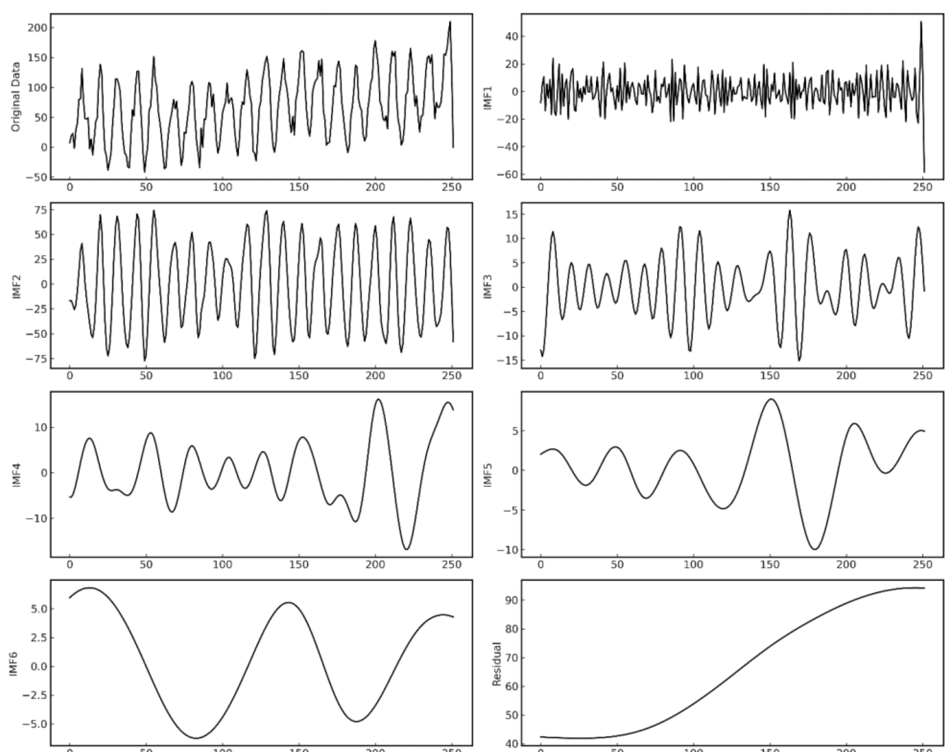

Figure 27. Mati City MSL fluctuation with the trend obtained using ICEEMDAN

5.7. Coastal zone vulnerability assessment score

Figure 28 displays the spatial distributions of the CVAs of Davao City (left) and Mati city (right). Table 25 illustrates the percentage of each class in the CVA assessment of the two cities. The CVA assessment combines six (6) factors: the SLR, elevation, geomorphology, SCR, SLCR, SWH, and SST. The CVA has five classes. A very low vulnerability represents the lowest vulnerability, followed by low, moderate, high, and very high vulnerability. The very high vulnerability signifies the highest vulnerability in the coastal areas of the two cities. The accuracy of the CVA in these two cities is acceptable, with accuracy rates of 80.07% and 88.24%, respectively. The CVA score of Mati City and Davao City is 1.62 and 1.63, respectively, showing low vulnerable to the changing coastal environment.

The majority of the coastline of Mati city has a moderate CVA of 58%, which signifies a substantial portion of the coast of Mati city, approximately 109 km. The areas under Classes 4 and 5, approximately 32.3% of the coastline, indicate regions of greater vulnerability. These areas are sand beaches with low elevations facing the Pacific Ocean, as shown in the figure. These areas need immediate attention, conservation efforts, or infrastructure development to handle potential threats. Classes 1 and 2, representing a smaller portion of the coast (~10%), should be noted. Continuous monitoring can ensure that these areas do not transition to higher vulnerability classes.The majority of the coastal areas in Davao City have moderate to high CVAs, with values of approximately 25.21% (19,41 km) and 32.54% (25.05 km), respectively. These two levels are areas under critical vulnerability. The very high CVA should be addressed since it covers 20% of the coastline and is a critically vulnerable area. These zones require immediate interventions to mitigate potential adverse impacts.

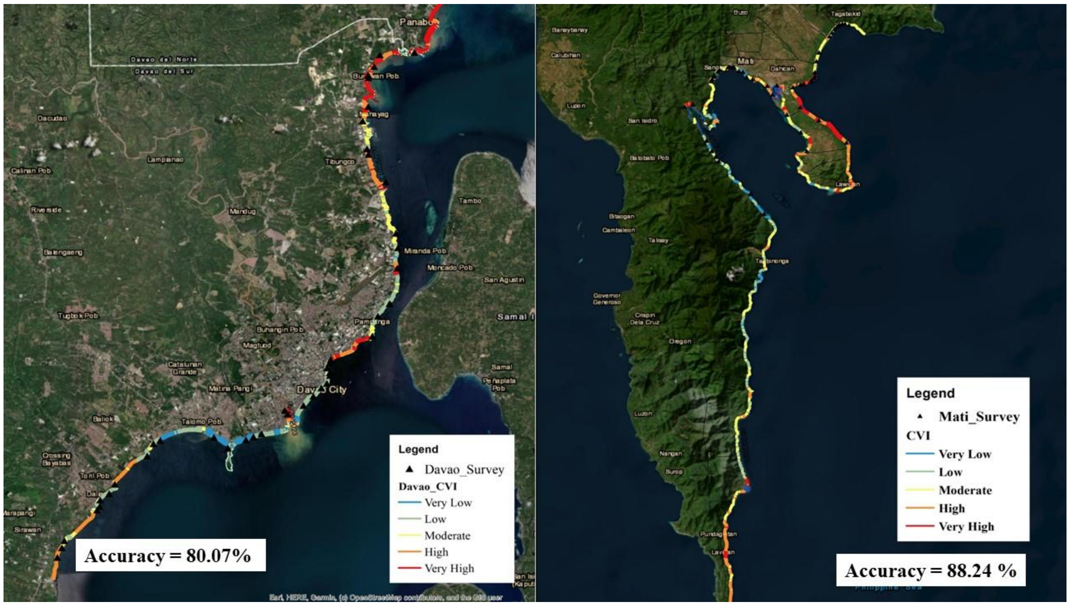

Figure 28. Coastal vulnerability index results for Davao City (left) and Mati City (right).

Table 24. Coastal vulnerability assessment for the two cities.

Class	Length (km)		Percentage (%)	
	Davao	Mati	Davao	Mati
Very Low	7.74	1.59	10.05	0.84
Low	9.71	16.67	12.61	8.82
Moderate	19.41	109.70	25.21	58.04
High	25.05	43.39	32.54	22.96
Very High	15.09	17.65	19.59	9.34

Chapter 6 - Development of the Expert-driven CRA Framework

The new feature of this framework compared to the OHI framework developed by Halpern et al. (2012) is the multicriteria analysis, where the judgment of the decision-makers is quantified. The AHP approach under the MCDA ensures the consistency of the respondents' judgment to ensure that the decision is acceptable and reasonable.

This paper implemented a purposive sampling approach in which the target respondents were employees in a city local government unit (LGU). After data screening and validation of the responses using the prescribed criteria ratio in the AHP, four (4) responses were excluded, and a total of twenty-three (23) responses were found to be valid for the analysis.

The researcher followed the process of the AHP. The analysis was classified into three parts. These are research and academicians, DMs (i.e., Planning Officer, Economist, Management Officer, Engineer), and the results based on the city. The consistency of the responses was also evaluated using the CR to ensure that the indices were correct and that the judgments were coherent. The subsequent subsections are the processes and results of each classification.

6.1. City-based societal development views

This section describes the perceptions of the decision makers in their development plans based on the four criteria. Tables 26, 27, 28, 29, 30, 31 and 32 are the normalized matrices for Mati, Davao, Cagayan De Oro, Cebu, Puerto Princesa, Metro Manila, and Laoag, respectively. The corresponding pairwise comparison matrix for each normalized matrix can be found in the Appendix.

Table 25. Normalized matrix for Mati City.

Criteria	C	NE	E	SE	Weights
Conservationist (C)	0.70	0.77	0.68	0.47	0.66
Non-Extractive (NE)	0.12	0.13	0.20	0.24	0.17
Extractive (E)	0.10	0.06	0.10	0.24	0.12
Strongly Extractive (SE)	0.09	0.03	0.02	0.06	0.05
SUM	1.00	1.00	1.00	1.00	1.00

Table 26. Normalized matrix for Davao City.

Criteria	C	NE	E	SE	Weights
Conservationist (C)	0.58	0.64	0.58	0.39	0.55
Non-Extractive (NE)	0.14	0.16	0.19	0.22	0.18
Extractive (E)	0.19	0.16	0.19	0.33	0.22
Strongly Extractive (SE)	0.08	0.04	0.03	0.06	0.05
SUM	1.00	1.00	1.00	1.00	1.00

Table 27. Normalized matrix for Cagayan De Oro City.

Criteria	C	NE	E	SE	Weights
Conservationist (C)	0.43	0.38	0.54	0.25	0.40
Non-Extractive (NE)	0.21	0.19	0.14	0.25	0.20
Extractive (E)	0.21	0.38	0.27	0.42	0.32
Strongly Extractive (SE)	0.14	0.06	0.05	0.08	0.09
SUM	1.00	1.00	1.00	1.00	1.00

Table 28. Normalized matrix for Cebu City.

Criteria	C	NE	E	SE	Weights
Conservationist (C)	0.48	0.52	0.47	0.36	0.46
Non-Extractive (NE)	0.24	0.26	0.32	0.27	0.27
Extractive (E)	0.16	0.13	0.16	0.27	0.18
Strongly Extractive (SE)	0.12	0.09	0.05	0.09	0.09
SUM	1.00	1.00	1.00	1.00	1.00

Table 29. Normalized matrix for Puerto Princesa City.

Criteria	C	NE	E	SE	Weights
Conservationist (C)	0.43	0.50	0.43	0.33	0.42
Non-Extractive (NE)	0.21	0.25	0.29	0.33	0.27
Extractive (E)	0.14	0.13	0.14	0.17	0.14
Strongly Extractive (SE)	0.21	0.13	0.14	0.17	0.16
SUM	1.00	1.00	1.00	1.00	1.00

Table 30. Normalized matrix for Metro Manila City.

Criteria	C	NE	E	SE	Weights
Conservationist (C)	0.55	0.63	0.56	0.36	0.53
Non-Extractive (NE)	0.14	0.16	0.19	0.27	0.19
Extractive (E)	0.18	0.16	0.19	0.27	0.20
Strongly Extractive (SE)	0.14	0.05	0.06	0.09	0.09
SUM	1.00	1.00	1.00	1.00	1.00

Table 31. Normalized matrix for Laoag City.

Criteria	C	NE	E	SE	Weights
Conservationist (C)	0.39	0.55	0.37	0.25	0.39
Non-Extractive (NE)	0.10	0.14	0.19	0.25	0.17
Extractive (E)	0.39	0.27	0.37	0.42	0.36
Strongly Extractive (SE)	0.13	0.05	0.07	0.08	0.08
SUM	1.00	1.00	1.00	1.00	1.00

Mati, Davao, Cagayan de Oro, Cebu, Puerto Princesa, Metro Manila, and Laoag have CR values of 0.087, 0.043, 0.058, 0.033, 0.017, 0.046, and 0.064, respectively. All the CR values are less than 0.10 or 10%, indicating that the results are reasonably acceptable. Figure 31 shows the percentage of each criterion according to the city. Overall, the Philippines is a conservationist, with a rating of 47.7%, followed by extractive, non-extractive, and strongly extractive, with ratings of 23.9%, 19.7%, and 8.7%, respectively. However, Mati city has the highest conservation criterion value of any city, indicating that the environment is important to the city. Furthermore, Mati city and Puerto Princesa are the only cities that place high value on non-extractive criteria.

This means that, while the city is developing, they are more concerned with the environment as a means of achieving success. These two cities are classified as naturally beautiful. Mati city is home to a UNESCO Natural Heritage Site and three of the world's most beautiful bays. Additionally, Puerto Princesa is home to the most picturesque islands and underground rivers. In contrast, other cities are urbanized cities.

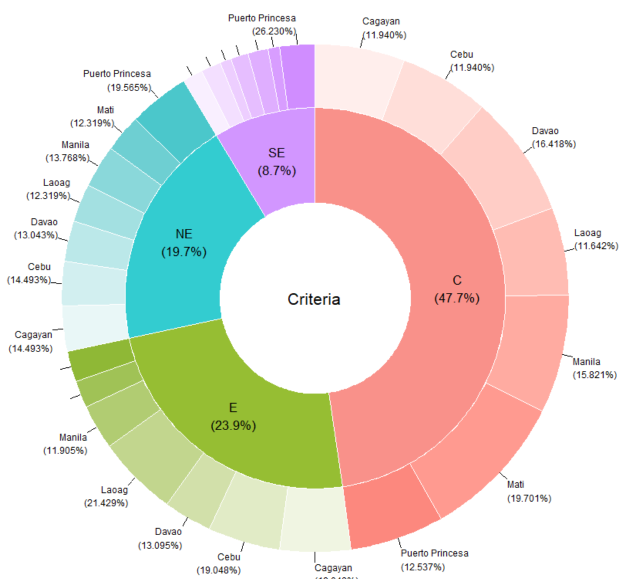

Figure 29. Expert-driven criteria analysis for the seven coastal cities.

6.2. The development of the CRA framework for each coastal city

This section describes how the CRA framework was developed from the perspective of each coastal city. The tables in this section show the pairwise comparison matrix with indicator weights. The normalized matrix is no longer shown in this section, but it can be computed quickly using the AHP approach described in the methodology section. Tables 33, 34, 35, 36, 37, 38 and 39 show the pairwise comparison matrices for Mati city, Davao City, Cagayan de Oro city, Cebu City, Puerto Princesa city, Metro Manila, and Laoag City, respectively.

Table 32. Pairwise comparison matrix with indicator weights for Mati City (CR = 0.099).

Indicator	NP	F	B	MC	TR	CS	CW	CL	SP	CP	Weight
NP	1.00	3.00	4.00	4.00	5.00	4.00	3.00	4.00	4.00	4.00	0.25
F	0.33	1.00	4.00	4.00	3.00	3.00	3.00	3.00	3.00	3.00	0.17
B	0.25	0.25	1.00	4.00	4.00	4.00	3.00	4.00	4.00	4.00	0.15
MC	0.25	0.25	0.25	1.00	4.00	3.00	3.00	3.00	3.00	3.00	0.11
TR	0.20	0.33	0.25	0.25	1.00	3.00	3.00	2.00	2.00	2.00	0.08
CS	0.25	0.33	0.25	0.33	0.33	1.00	2.00	2.00	2.00	2.00	0.06
CW	0.33	0.33	0.33	0.33	0.33	0.50	1.00	3.00	2.00	2.00	0.06
CL	0.25	0.33	0.25	0.33	0.50	0.50	0.33	1.00	2.00	2.00	0.04
SP	0.25	0.33	0.25	0.33	0.50	0.50	0.50	0.50	1.00	1.00	0.04
CP	0.25	0.33	0.25	0.33	0.50	0.50	0.50	0.50	1.00	1.00	0.04
Sum	3.37	6.50	10.83	14.92	19.17	20.00	19.33	23.00	24.00	24.00	1.00

Table 33. Pairwise comparison matrix with indicator weights for Davao City (CR = 0.095).

Indicator	NP	F	B	MC	TR	CS	CW	CL	SP	CP	Weight
NP	1.00	4.00	5.00	4.00	3.00	4.00	4.00	4.00	4.00	4.00	0.27
F	0.17	1.00	5.00	5.00	4.00	3.00	3.00	3.00	3.00	3.00	0.18
B	0.20	0.20	1.00	4.00	4.00	3.00	3.00	3.00	3.00	3.00	0.14
MC	0.25	0.20	0.25	1.00	4.00	4.00	3.00	3.00	3.00	3.00	0.12
TR	0.33	0.25	0.25	0.25	1.00	2.00	2.00	2.00	2.00	2.00	0.07
CS	0.25	0.33	0.33	0.25	0.50	1.00	2.00	2.00	2.00	2.00	0.06
CW	0.25	0.33	0.33	0.33	0.50	0.50	1.00	2.00	1.00	1.00	0.04
CL	0.25	0.33	0.33	0.33	0.50	0.50	0.50	1.00	1.00	1.00	0.04
SP	0.25	0.33	0.33	0.33	0.50	0.50	1.00	1.00	1.00	1.00	0.04
CP	0.25	0.33	0.33	0.33	0.50	0.50	1.00	1.00	1.00	1.00	0.04
Sum	3.20	9.32	13.17	15.83	18.50	19.00	20.50	22.00	21.00	21.00	1.00

Table 34. Pairwise comparison matrix with indicator weights for Cagayan (CR = 0.097).

Indicator	NP	F	B	MC	TR	CS	CW	CL	SP	CP	Weight
NP	1.00	3.00	2.00	4.00	4.00	3.00	2.00	3.00	5.00	2.00	0.23
F	0.25	1.00	2.00	2.00	4.00	3.00	1.00	1.00	3.00	2.00	0.13
B	0.50	0.50	1.00	3.00	7.00	3.00	2.00	4.00	3.00	3.00	0.17
MC	0.25	0.50	0.33	1.00	3.00	2.00	2.00	2.00	2.00	2.00	0.09
TR	0.25	0.25	0.14	0.33	1.00	2.00	1.00	1.00	1.00	2.00	0.06
CS	0.33	0.33	0.33	0.50	0.50	1.00	3.00	3.00	2.00	4.00	0.09
CW	0.50	1.00	0.50	0.50	1.00	0.33	1.00	3.00	2.00	3.00	0.09
CL	0.33	1.00	0.25	0.50	1.00	0.33	0.33	1.00	2.00	2.00	0.06
SP	0.20	0.33	0.33	0.50	1.00	0.50	0.50	0.50	1.00	1.00	0.04
CP	0.50	0.50	0.33	0.50	0.50	0.25	0.33	0.50	1.00	1.00	0.04
Sum	4.12	9.42	7.23	12.83	23.00	15.42	13.17	19.00	22.00	22.00	1.00

Table 35. Pairwise comparison matrix with indicator weights for Cebu City (CR = 0.081).

Indicator	NP	F	B	MC	TR	CS	CW	CL	SP	CP	Weight
NP	1.00	2.00	3.00	4.00	4.00	5.00	5.00	6.00	6.00	7.00	0.27
F	0.50	1.00	2.00	2.00	3.00	3.00	4.00	4.00	5.00	6.00	0.17
B	0.33	0.50	1.00	3.00	3.00	4.00	4.00	5.00	6.00	7.00	0.16
MC	0.25	0.50	0.33	1.00	2.00	2.00	3.00	3.00	4.00	5.00	0.10
TR	0.25	0.33	0.33	0.50	1.00	3.00	3.00	4.00	4.00	5.00	0.09
CS	0.20	0.33	0.25	0.50	0.33	1.00	3.00	3.00	3.00	4.00	0.07
CW	0.20	0.25	0.25	0.33	0.33	0.33	1.00	3.00	4.00	4.00	0.05
CL	0.17	0.25	0.20	0.33	0.25	0.33	0.33	1.00	3.00	5.00	0.04
SP	0.17	0.20	0.17	0.25	0.25	0.33	0.25	0.33	1.00	4.00	0.03
CP	0.14	0.17	0.14	0.20	0.20	0.25	0.25	0.20	0.25	1.00	0.02
Sum	3.21	5.53	7.68	12.12	14.37	19.25	23.83	29.53	36.25	48.00	1.00

Table 36. Pairwise comparison matrix with indicator weights for Princesa City (CR = 0.067).

Indicator	NP	F	B	MC	TR	CS	CW	CL	SP	CP	Weight
NP	1.00	1.00	1.00	2.00	2.00	3.00	3.00	3.00	4.00	6.00	0.17
F	1.00	1.00	1.00	2.00	2.00	3.00	3.00	3.00	4.00	5.00	0.17
B	1.00	1.00	1.00	1.00	2.00	2.00	3.00	3.00	3.00	5.00	0.14
MC	0.50	0.50	1.00	1.00	5.00	1.00	2.00	8.00	6.00	5.00	0.16
TR	0.50	0.50	0.50	0.20	1.00	3.00	3.00	3.00	4.00	4.00	0.11
CS	0.33	0.33	0.50	1.00	0.33	1.00	3.00	4.00	4.00	4.00	0.10
CW	0.33	0.33	0.33	0.50	0.33	0.33	1.00	2.00	2.00	3.00	0.06
CL	0.33	0.33	0.33	0.13	0.33	0.25	0.50	1.00	3.00	3.00	0.05
SP	0.25	0.25	0.33	0.17	0.25	0.25	0.50	0.33	1.00	2.00	0.03
CP	0.17	0.20	0.20	0.20	0.25	0.25	0.33	0.33	0.50	1.00	0.02
Sum	5.42	5.45	6.20	8.19	13.50	14.08	19.33	27.67	31.50	38.00	1.00

Table 37. Pairwise comparison matrix with indicators weights for Manila City (CR = 0.091).

Indicator	NP	F	B	MC	TR	CS	CW	CL	SP	CP	Weight
NP	1.00	4.00	1.00	4.00	4.00	2.00	1.00	2.00	3.00	2.00	0.19
F	0.25	1.00	2.00	3.00	3.00	2.00	1.00	1.00	3.00	1.00	0.13
B	1.00	0.50	1.00	4.00	7.00	2.00	2.00	4.00	4.00	2.00	0.18
MC	0.25	0.33	0.25	1.00	2.00	1.00	1.00	2.00	1.00	1.00	0.07
TR	0.25	0.33	0.14	0.50	1.00	1.00	1.00	1.00	1.00	2.00	0.06
CS	0.50	0.50	0.50	1.00	1.00	1.00	3.00	3.00	2.00	4.00	0.12
CW	1.00	1.00	0.50	1.00	1.00	0.33	1.00	3.00	3.00	2.00	0.10
CL	0.50	1.00	0.25	0.50	1.00	0.33	0.33	1.00	2.00	2.00	0.06
SP	0.33	0.33	0.25	1.00	1.00	0.50	0.33	0.50	1.00	1.00	0.04
CP	0.50	1.00	0.50	1.00	0.50	0.25	0.50	0.50	1.00	1.00	0.05
Sum	5.58	10.00	6.39	17.00	21.50	10.42	11.17	18.00	21.00	18.00	1.00

Table 38. Pairwise comparison matrix with indicator weights for Laoag City (CR = 0.099).

Indicator	NP	F	B	MC	TR	CS	CW	CL	SP	CP	Weight
NP	1.00	7.00	3.00	5.00	6.00	6.00	2.00	4.00	6.00	4.00	0.29
F	0.14	1.00	3.00	2.00	5.00	6.00	2.00	2.00	2.00	2.00	0.16
B	0.33	0.33	1.00	4.00	5.00	5.00	2.00	3.00	3.00	3.00	0.15
MC	0.20	0.50	0.25	1.00	3.00	2.00	2.00	2.00	2.00	3.00	0.09
TR	0.17	0.20	0.20	0.33	1.00	2.00	2.00	2.00	2.00	1.00	0.06
CS	0.17	0.17	0.20	0.50	0.50	1.00	2.00	1.00	1.00	2.00	0.05
CW	0.50	0.50	0.50	0.50	0.50	0.50	1.00	2.00	2.00	3.00	0.07
CL	0.25	0.50	0.33	0.50	0.50	1.00	0.50	1.00	2.00	1.00	0.05
SP	0.17	0.50	0.33	0.50	0.50	1.00	0.50	0.50	1.00	1.00	0.04
CP	0.25	0.50	0.33	0.33	1.00	0.50	0.33	1.00	1.00	1.00	0.04
Sum	3.18	11.20	9.15	14.67	23.00	25.00	14.33	18.50	22.00	21.00	1.00

The CRA framework is based on the indicator weights in every city. Every city has an index showing that the framework's generation relies on the perception of every city and the type of development of the city they wanted. Figure 32 shows the top indicators by city. Moreover, the framework for each city is presented in Equations (10)-(16).

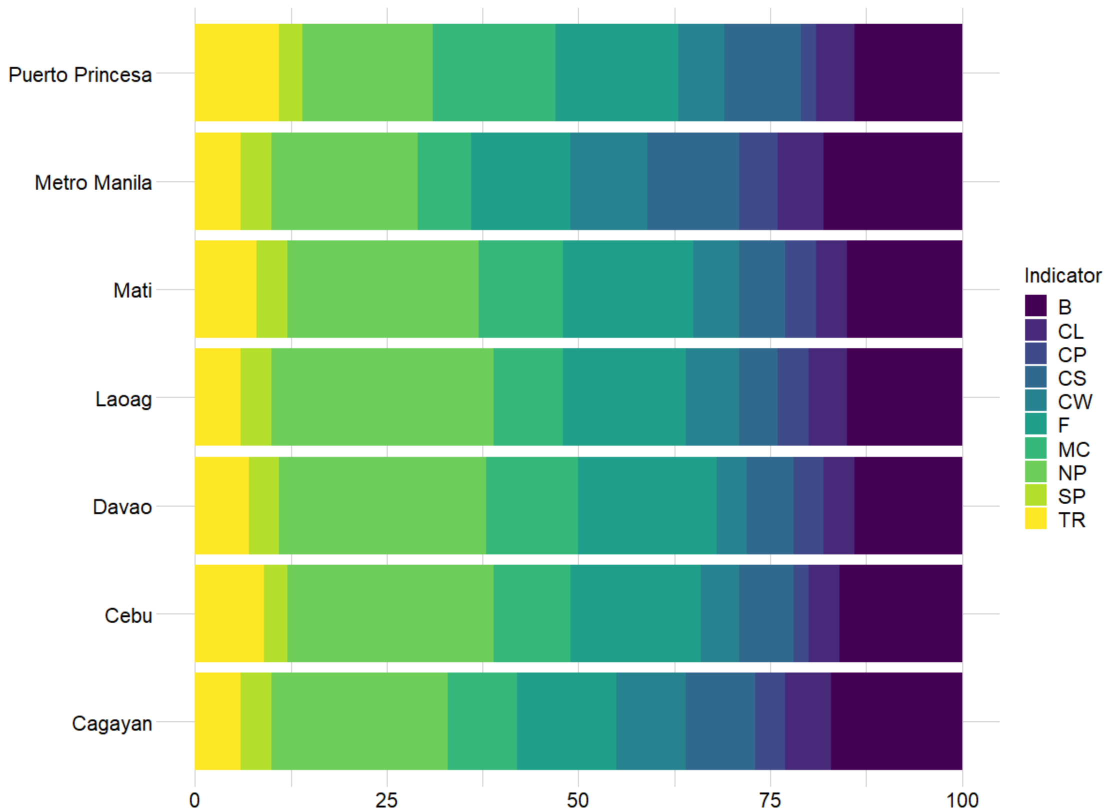

Figure 30. The expert-driven CRA framework relative weights of indicators.

$$\begin{aligned} CRA_{Mat.} = {} & NP \times 0.25 + F \times 0.17 + B \times 0.15 + MC \times 0.11 \\ & + TR \times 0.08 + CS \times 0.06 + CW \times 0.06 + CL \times 0.04 \\ & + SP \times 0.04 + CP \times 0.04 \end{aligned} \tag{10}$$

$$\begin{aligned} CRA_{Dav.} = {} & NP \times 0.27 + F \times 0.18 + B \times 0.14 + MC \times 0.12 \\ & + TR \times 0.07 + CS \times 0.06 + CW \times 0.04 + CL \times 0.04 \\ & + SP \times 0.04 + CP \times 0.04 \end{aligned} \tag{11}$$

$$\begin{aligned} CRA_{Cag.} = {} & NP \times 0.23 + F \times 0.13 + B \times 0.17 + MC \times 0.09 \\ & + TR \times 0.06 + CS \times 0.09 + CW \times 0.09 + CL \times 0.06 \\ & + SP \times 0.04 + CP \times 0.04 \end{aligned} \tag{12}$$

$$\begin{aligned} CRA_{Ceb.} = {} & NP \times 0.27 + F \times 0.17 + B \times 0.16 + MC \times 0.10 + TR \times 0. \\ & + CS \times 0.07 + CW \times 0.05 + CL \times 0.04 + SP \times 0.03 \\ & + CP \times 0.02 \end{aligned} \tag{13}$$

$$\begin{aligned} CRA_{Pue.} = {} & NP \times 0.17 + F \times 0.17 + B \times 0.14 + MC \times 0.16 \\ & + TR \times 0.11 + CS \times 0.10 + CW \times 0.06 + CL \times 0.05 \\ & + SP \times 0.03 + CP \times 0.02 \end{aligned} \tag{14}$$

$$CRA_{Met.} = NP \times 0.18 + F \times 0.13 + B \times 0.18 + MC \times 0.07 + TR \times 0.06 + CS \times 0.12 + CW \times 0.10 + CL \times 0.06 + SP \times 0.04 + CP \times 0.05 \quad (15)$$

$$CRA_{Lao.} = NP \times 0.29 + F \times 0.16 + B \times 0.15 + MC \times 0.09 + TR \times 0.06 + CS \times 0.05 + CW \times 0.07 + CL \times 0.05 + SP \times 0.04 + CP \times 0.04 \quad (16)$$

6.3. Views of decision-makers' societal development

This section discusses how DMs perceive societal development views. Tables 40 and 41 show the pairwise comparison and normalized matrix for this category. The weights for C, NE, E, and SE are 0.46, 0.18, 0.29, and 0.08, respectively. The consistency ratio is 9.8%. The respondents appear to be conservationists and extractors. The findings indicate that the majority of DMs prefer an extractive approach to development.

Table 39. Pairwise comparison matrix for the decision makers.

Criteria	C	NE	E	SE
Conservationist (C)	1	3	2	4
Non-Extractive (NE)	0.33	1	0.5	3
Extractive (E)	0.50	2.00	1	4
Strongly Extractive (SE)	0.25	0.33	0.25	1
Sum	2.08	6.33	3.75	12

Table 40. Normalized matrix with the criteria weights for the decision makers (CR=0.098).

Criteria	C	NE	E	SE	Weights
Conservationist (C)	0.48	0.47	0.53	0.33	0.46
Non-Extractive (NE)	0.16	0.16	0.13	0.25	0.18
Extractive (E)	0.24	0.32	0.27	0.33	0.29
Strongly Extractive (SE)	0.12	0.05	0.07	0.08	0.08
Sum	1.00	1.00	1.00	1.00	1.00

6.4. The development of the CRA framework for educators and researchers.

This section presents the CRA framework for educators and researchers. Table 42 displays the pairwise comparison matrix along with the weights of the indicators. The researchers and educators prioritized NP (20%), B (16%), F (15%), CW (11%), and MC (8%). Equation 17 depicts the CRA framework for these respondents, which has an acceptable consistency rating of 9.5%. Additionally, Figure 33 shows the percentage rating per indicator.

Table 41. Pairwise comparison matrix for the educators and researchers. CR=0.095

Indicator	NP	F	B	MC	TR	CS	CW	CL	SP	CP	Weights
Natural Products (NP)	1.00	3.00	2.00	4.00	5.00	3.00	1.00	3.00	4.00	2.00	0.20
Fisheries (F)	0.33	1.00	2.00	3.00	5.00	4.00	1.00	1.00	4.00	2.00	0.15
Biodiversity (B)	0.50	0.50	1.00	4.00	6.00	4.00	2.00	4.00	3.00	1.00	0.16
Marine Culture (MC)	0.25	0.33	0.25	1.00	3.00	2.00	1.00	2.00	2.00	1.00	0.08
Tourism & Recreation (TR)	0.20	0.20	0.17	0.33	1.00	2.00	1.00	1.00	2.00	1.00	0.06
Carbon Storage (CS)	0.33	0.25	0.25	0.50	0.50	1.00	1.00	3.00	3.00	1.00	0.07
Clean Water (CW)	1.00	1.00	0.50	1.00	1.00	1.00	1.00	4.00	4.00	1.00	0.11
Coastal Livelihood (CL)	0.33	1.00	0.25	0.50	1.00	0.33	0.25	1.00	3.00	1.00	0.06
Sense of Place (SP)	0.25	0.25	0.33	0.50	0.50	0.33	0.25	0.33	1.00	1.00	0.04
Coastal Protection (CP)	0.50	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.07
Sum	4.70	8.03	7.75	15.83	24.00	18.67	9.50	20.3	27.0	12.00	1.00

$$CoZHI = NP \times 0.20 + F \times 0.15 + B \times 0.16 + MC \times 0.08 + TR \times 0.06 + CS \times 0.07 + CW \times 0.11 + CL \times 0.06 + SP \times 0.04 + CP \times 0.07 \quad (17)$$

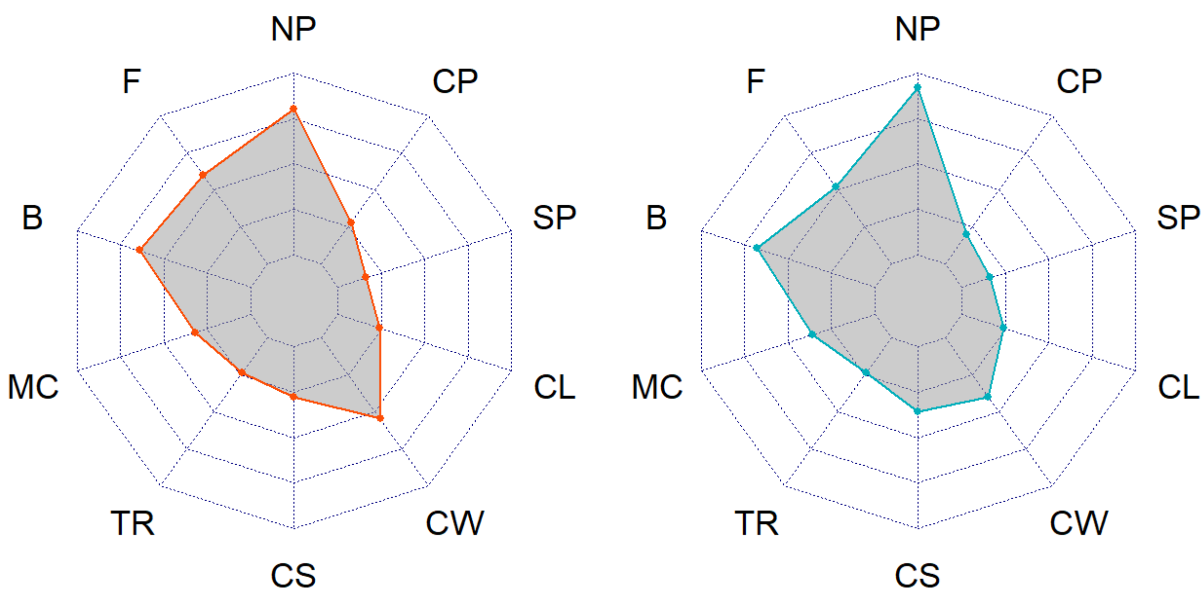

Figure 31. CRA expert-driven relative weights of indicators from (left) the educator's and researcher’s perspective and (right) the decision-maker’s perspective.

Chapter 7 - The CoZHI assessment

7.1. The 2023 CRA score

The coastal resource assessment index (CRA) score for 2023 compares how two cities (i.e., Mati and Davao) manage and sustain the delivery of coastal zone benefits. By evaluating a range of indicators, namely, Fisheries, Mariculture, Water Quality, Biodiversity, Carbon Storage, Coastal Livelihood, Tourism and Recreation, Sense of Place, and Natural Products, the CRA framework offers a detailed view of each city's performance in these areas. The overall score for each city is derived by aggregating these indicators utilizing specific equations. The values of Equation 6 for Mati City and Equation 7 for Davao City are shown in Table 47.

The CRA scores are 52 for Mati and 60 for Davao, indicating a slight variation in how each city manages its coastal zone environment, with Davao City achieving a marginally higher score than Mati. These scores suggest that both cities exhibit a moderate level of effectiveness in coastal zone management while also pinpointing areas where each can enhance their practices to improve sustainability and the delivery of coastal benefits. For instance, the coastal livelihoods (21%), fisheries (33%), natural products (33%), tourism and recreation (42%), and mariculture production (44%) of Mati city need to be improved. The city of Davao has tourism and recreation (32%), marine culture (32%), and coastal livelihoods (36%). These are areas below fifty percent that need to improve for the two cities.

Table 42. The CRA index score.

Indicators	Mati	Davao
Fisheries	33	57
Marine Culture	44	32
Water Quality	97	89
Biodiversity	61	72
Carbon Storage	61	72
Coastal Protection	61	72
Coastal Livelihood	21	36
Tourism and Recreation	42	32
Sense of Place	80	88
Natural Products	33	57
SCORE	**52**	**60**

7.2. Integrated framework for CRA and CVA assessment

This framework applied MCDA, where the judgment of policymakers is quantified. The AHP approach under the MCDA ensures the consistency of the respondents' judgment to ensure that the decision is acceptable and reasonable (Saaty, 1980). The coastal cities of Mati city and Davao City in the Philippines were selected as the study areas. The researcher followed the AHP method. The following paragraphs are the results of each classification. Figure 34 shows the societal views of each city based on the four criteria. These criteria were defined in the study by Cabrera & Lee (2022).

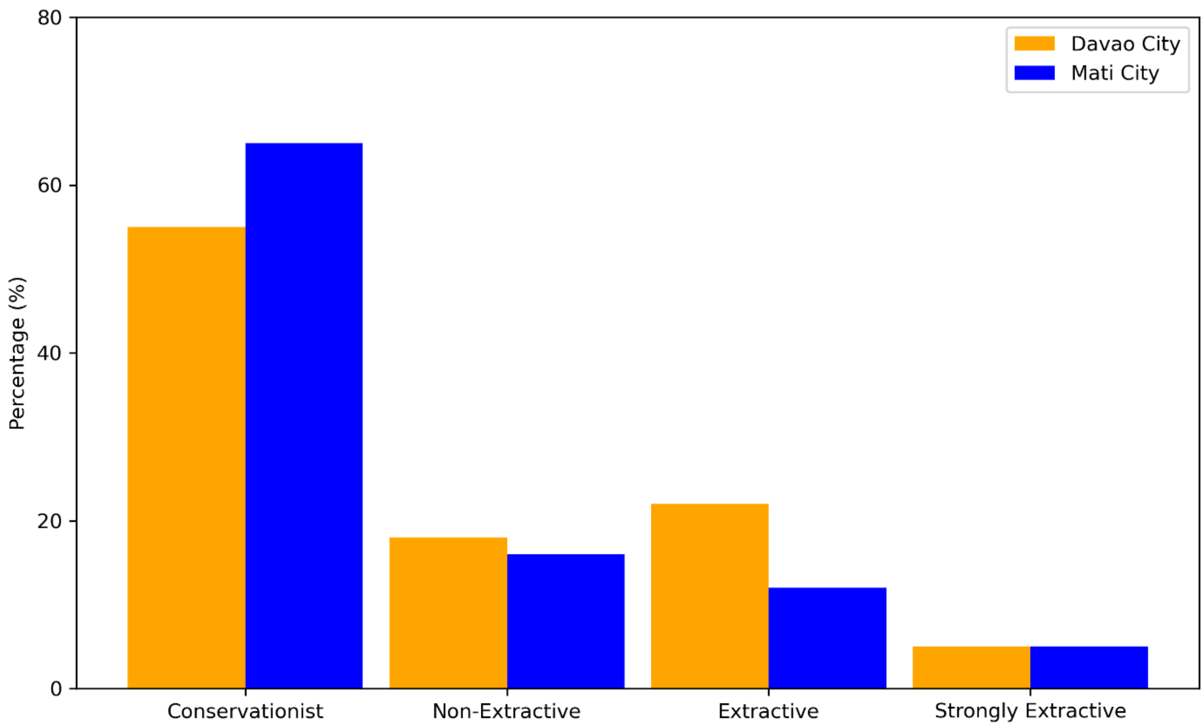

Figure 32. The societal development views of the two cities

The criteria ratios (CRs) for Mati and Davao are 8.7% and 4.3%, respectively, which are reasonably acceptable. The city of Davao is a conservationist (55%) yet extractive (22%) city and a little empathizes in non-extractive (18%) and strongly extractive (5%) cities. However, Mati city, on the other hand, scores higher on the environmentalist criterion, indicating that the environment is vital to the city. Moreover, non-extractive characteristics are highly valued in Mati City. It follows that despite a city's development goals, environmental concerns are a greater factor in its success. Mati city is the home of the Mt. Hamiguitan UNESCO Heritage Site. In contrast, Davao City is an urbanized city.

The indicator weights in each city serve as the foundation of the CRA framework. The complete definition of each indicator is provided in the study by Cabrera & Lee (2022). Figure 35 shows the relative weights of each indicator. Furthermore, the framework is depicted in Equations 5 and 6. Table 43 in the previous subsection shows the individual score of each indicator and the CRA. The CRA values of Mati city and Davao City are 52% and 60%, respectively.

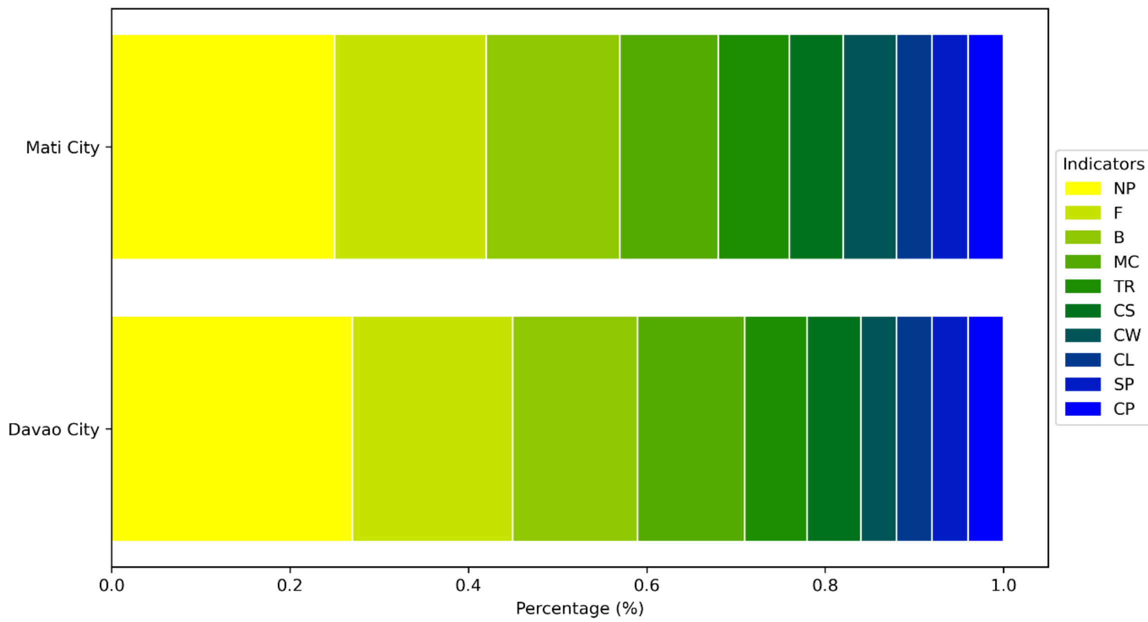

Figure 33. Relative weights of indicators for the two coastal cities

The coastal vulnerability assessments of Davao City and Mati city revealed moderate to high and moderate classifications, with model accuracies of 80.07% and 88.24%, respectively. In Davao City, ten towns with at least 193,853 people are at least highly vulnerable, while five towns with 97,995 people are highly vulnerable in Mati. The CVAs of Mati city and Davao City are 1.62 and 1.63, respectively. These results show that the two cities are at low risk of changing coastal environments.

This last section addresses the integration of the two indices (i.e., the CRA and CVA). The two indices will be combined. The CRA is a measure of the productivity of the coastal zone environment. Moreover, the CVA is used to assess the susceptibility of coastal zone areas to hazards. Unfortunately, the two have different units; the CRA is expressed as a percentage, while the CVA is a categorical value representing risk ratings. One common technique for normalizing categorical data is one-hot encoding. Each category has a binary indicator. A value of 1 is assigned for the category to which the observation belongs, and 0 is assigned for all other categories. The risk ratings for each category are as follows: very low [1,0,0,0,0], low [0,1,0,0,0], moderate [0,0,1,0,0], high [0,0,0,1,0], and very high [0,0,0,0,0,1]. The values of each category are assumed to be 100%, 80%, 60%, 40%, and 20% for Very Low, Low, Moderate, High, and Very High, respectively. The variance in each category is 20%. The CVAs of Mati and Davao City are 1.62 and 1.63, respectively. Therefore, the one-hot encoding of the two cities is very low [1,0,0,0,0], and it is 100%. This percentage is not 100% because there are still remaining point values (0.62 and 0.63). The remaining 0.62 and 0.63 will be multiplied by the variance of the category, which is 20. A total of 62% of 20 had a value of 12.4, and 63% of 20 had a value of 12.6. The final CVA of Mati City is 87.6 (i.e., 100-12.4), while that of Davao City is 87.4 (i.e., 100-12.6). The two indices have the same units.

The final integrated coastal zone framework index (CoZHI) score includes three cases. The first case is the average score of the CRA and CVA. In the second case, the CRA score is highly important. The third case is giving high importance to CVA. The MCDA-AHP was applied to compute the final scores of Cases 2 and 3. Table 44 shows the results for Cases 2 and 3. The weights of the CRA and CVA in Case 2 are 67% and 33%, respectively. On the other hand, the weights of the CRA and CVA are 33% and 67%, respectively, in Case 3. The final integrated coastal zone health index score using Case 1 is 70% for Mati city and 74% for Davao City, as shown in Figure 36. Meanwhile, the scores in Case 2 for Mati City and Davao City are 64% and 69%, respectively (see Figure 37). Furthermore, the scores in Case 3 for Mati city are 76% and 78% for Davao City, as depicted in Figure 38.

Table 43. Comparison matrix for the integrated CoZHI framework including the weights.

Criteria	**Case 2**			**Case 3**		
	C1	**C2**	**Weigths**	**C1**	**C2**	**Weights**
CRA (C1)	1.00	2.00	0.67	1.00	0.50	0.33
CVA (C2)	0.50	1.00	0.33	2.00	1.00	0.67
SUM	1.50	3.00	1.00	3.00	1.50	1.00

Mati city is classified as having improved performance. This score highlights that below-average performance in significant areas requires improvement. These areas are coastal livelihoods, fisheries, mariculture, and natural products. Meanwhile, Davao City is satisfactory.

This means adequate performance, meeting basic requirements but requiring more concerted efforts to address the existing challenges. These challenges are related to mariculture, tourism and recreation, and coastal livelihoods. Addressing the challenges of these two cities will eventually increase the health and integrity of the corresponding coastal zone environment.

Returning to the definitions of the CRA and CVA, the CRA is a measure of the productivity of the coastal zone environment. Moreover, the CVA is used to assess the susceptibility of coastal zone areas to hazards. The integration of the two indices will determine which index should be given greater importance than the other index. The three cases provide us with a holistic understanding of the final integrated CoZHI score. Case 1 is a conservative evaluation emphasizing equal weights of the two criteria. Moreover, in Case 2, the 10 important indicators of the coastal zone environment are highly important, while a slight recognition of the importance of hazards will decrease the score compared with that in Case 1, as shown in Figures 36 and 37. This shows the importance of addressing the hazards that affect the health and integrity of the coastal zone environment. Furthermore, Case 3 confirms the results of Case 2. A high importance of the hazard component will increase the health of the coastal zone environment, as depicted in Figure 34 compared to Figure 38.

Figure 34. Integrated framework with equal weights. The CRA is orange and CVA is blue in color (Left: Mati City and Right: Davao City)

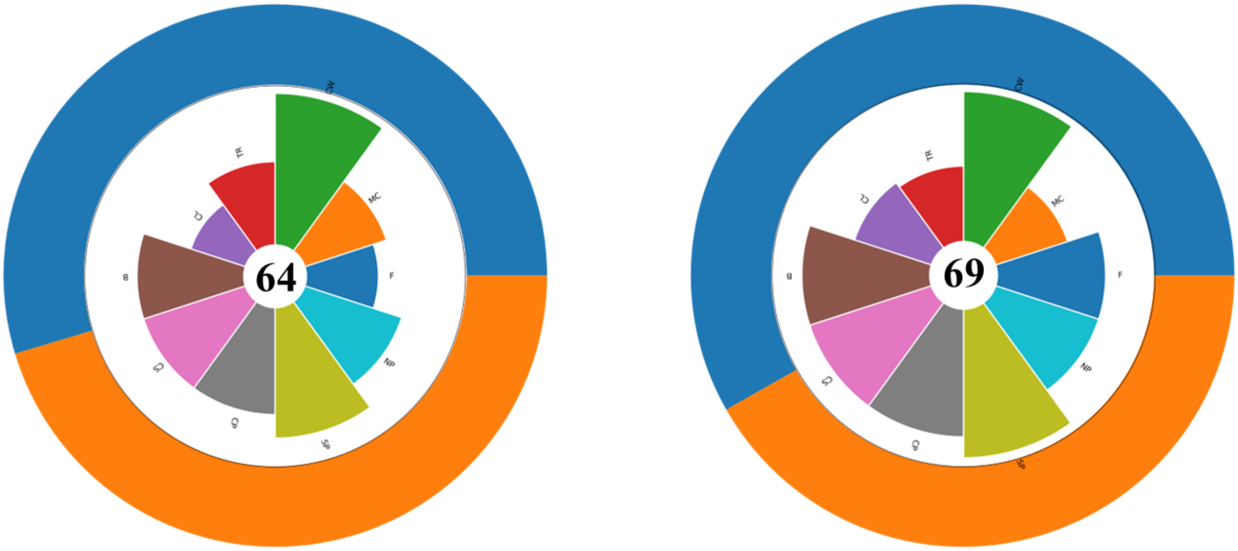

Figure 35. An integrated framework with high importance to the CRA.

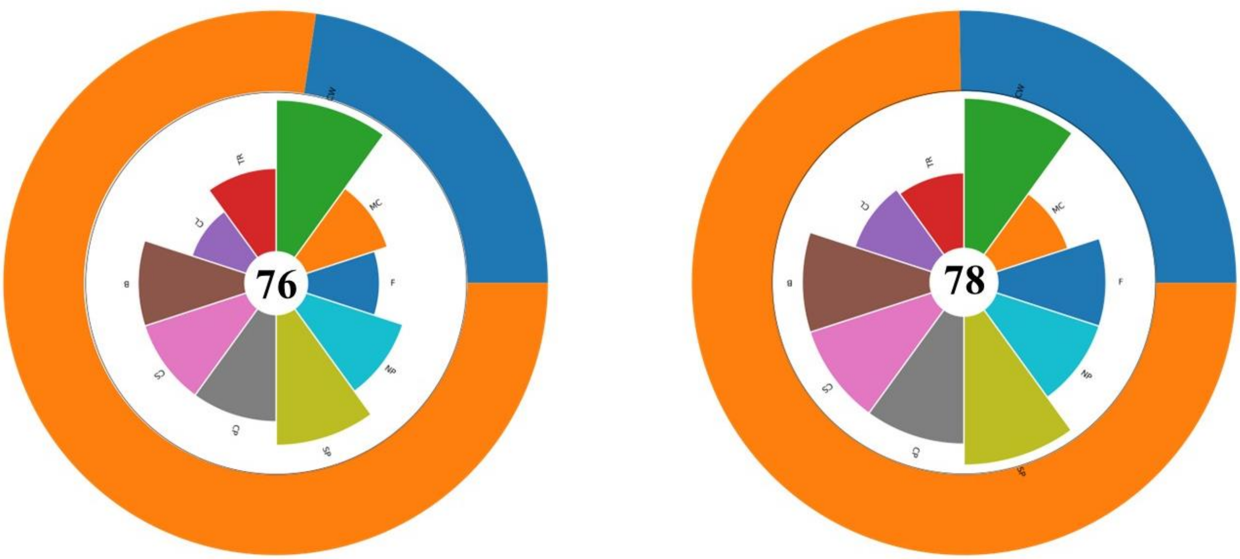

Figure 36. The integrated framework with high importance to the CVA.

Chapter 8 - Conclusions and Recommendations

8.1. Conclusions

8.1.1. CoZHI framework using MCDA-AHP

Every human has a different perspective on understanding the development of society. Furthermore, decision-makers and planners in local government units have different perspectives on city development. It is either environmentally friendly or not. Nevertheless, the perception of one city is different from that of another city. Thus, harmonious and holistic development should be considered.

In the modern era, the development plan is anchored to sustainable development where humans and nature coexist. This MCDA-AHP approach is an attempt to recognize the perceptions of individuals when designing the CoZHI framework for a sustainable coastal zone assessment plan. Thus, the framework in this study is adaptive to local governments' perceptions of governing bodies. The study revealed that the development plan of an individual city is highly connected to the nature of the city in which it is currently situated. Moreover, environmental educators and researchers are balancing decision-makers' perceptions. They are preserving nature, while decision-makers are pivoting to the extractive development of the city. It is essential that during the sustainable development planning of a city, an environmentalist should be involved to balance the plan where the development plan is directed to preserving the environment.

The evaluation of the importance of one indicator to another in the survey instrument is seen as the primary use of AHP. In some cases, as stated in the results section, respondents needed to be more consistent with their responses. Thus, an actual survey might need to elaborate on the concept of the questionnaire and how to respond to the questions to avoid confusion. Additionally, a triangulation technique should be used to validate the answers and ensure that all the responses are correct.

The study showcases the flexibility of the indices in the framework. The weight of a particular index in the framework differs from one city to another. Thus, before assessing each indicator's health in a particular study area, the framework is generated by conducting a survey using the approach presented in this study. Furthermore, in some cases, the framework is flexible in selecting the appropriate indicators to utilize in the respective study area. It might also happen that a particular indicator is not needed or that a new indicator can be introduced.

8.1.2. Coastal zone vulnerability and risk assessment.

The coastal vulnerability assessment was performed by CVA analysis using GIS and remote sensing technologies to measure the risk level of coastal areas in Mati and Davao City efficiently and appropriately, considering both geological and physical parameters. This study showed that geomorphology, shoreline change rate, and coastal elevation are the parameters that most contribute to determining coastal vulnerability since the sea level change rate was given the same risk level along the coast. The parameter with the greatest contribution could be further improved using weighted determination. In addition, the proposed index is feasible for assessing coastal vulnerability in other coastal areas when dealing with climate change.

Although some places are at high risk, Mati and Davao City have CVA scores of 1.62 and 1.63, respectively. The CVA map created for Mati and Davao City is useful for decision-makers in disaster mitigation and management. It aids efforts to reduce the effects of climate change. However, the study has shortcomings. The emphasis on remote sensing and GIS may not capture local variations that influence vulnerability assessments. Furthermore, assigning risk levels uniformly throughout coastal sections may generalize the complex interaction of factors impacting coastal vulnerability. Thus, can lead to underestimation or overestimation in some places.

8.1.3. The CRA score evaluation of the two cities.

The 2023 CRA score describes how two cities manage and offer the various benefits linked with their coastal zone environments. The CRA framework aggregates ten indicators, including Fisheries and Mariculture, Water Quality, Biodiversity, and more, into an overall health score for each city using expert-driven derived equations showing uniqueness in each city. The assessment scores of 47 for Mati and 53 for Davao underscore a moderate variation in coastal zone management effectiveness between the cities. This differential highlights the areas where each city excels and points to critical opportunities for enhancing its coastal management practices. The index scores of the two cities cannot be compared because each city has its own perspective of development, such that each indicator’s weight is different in every city.

The coastal livelihoods (21%), fisheries (33%), natural products (33%), tourism and recreation (42%), and mariculture production (44%) of Mati city need to be improved. The city of Davao has tourism and recreation (32%), marine culture (32%), and coastal livelihoods (36%). These are areas below fifty percent that need to improve for the two cities. The score for Tourism and Recreation is low because of the pandemic situation, yet programs, infrastructure, and financial support are in place. A well-balanced policy intervention for mariculture should be implemented if the city supports criteria to avoid destruction of the mangrove forest and the quality of seawater. In the case of Fisheries, Mati City should construct a Fish and Can Processing Plant so that all large fish, especially blue marines, should be processed inside Mati City and not in General Santos City. This recommendation will not only increase the health score of this indicator but also generate a livelihood in the coastal community.

These results will serve as a baseline for future coastal zone health score changes. This will also determine which criteria the city has given priority or not. Such insights are invaluable for guiding future strategies aimed at improving the sustainable management and utilization of coastal zone benefits, ultimately contributing to the ecological and socioeconomic well-being of the communities involved. Overall, I believe that human development can achieve a well-balanced state, enabling humans and the environment to coexist and preserve natural resources for future generations.

8.1.4. The integrated CRA and CVA assessment indices

This study involving the coastal cities of Mati and Davao in the Philippines provides significant insights into the dynamics of urban development and environmental conservation. Mati City, influenced by its proximity to the Mt. Hamiguitan UNESCO Heritage Site, places a higher priority on environmental conservation. This is reflected in its stronger focus on non-extractive and environmentalist criteria compared to Davao City, which exhibits a more balanced approach between conservation and economic extraction. This suggests that urban characteristics significantly influence environmental policies and community priorities.

The CRA and CVA assessments revealed moderate coastal health in both cities, with CRA scores of 47% for Mati and 53% for Davao. Moreover, both cities face low to moderate vulnerability to coastal hazards, as indicated by CVAs of 1.62 and 1.63, respectively. This highlights a risk to communities within these coastal zone regions and underscores the need for enhanced policy interventions to mitigate these vulnerabilities.

The integration of the CRA and CVA into a single framework allows for a comprehensive evaluation of the health and risks associated with coastal zones. To understand a broader perspective, three cases were studied. Case 1 is a conservative evaluation emphasizing equal weights of the two criteria. Meanwhile, in Case 2, the 10 essential indicators of the coastal zone environment are highly important, while a slight recognition of the importance of hazards will lower the score compared with that in Case 1. This shows that hazards can strongly affect the health of the coastal zone environment. Furthermore, Case 3 confirms the results of Case 2. The high importance of the hazard component will increase the health of coastal zone environments. These scenarios can be used by local governments to evaluate the health and integrity of their own coastal zone environment. Additionally, they can adopt among the three cases depending on the score of each component in the CRA and CVA. If the CVA is very low, then Case 3 can be adopted; otherwise, Case 2 can be adopted. This will showcase the flexibility of the framework to address the problems and challenges in each city. Finally, these findings can guide local governments and policymakers in refining strategies for sustainable development, enhancing resilience against coastal hazards, and improving community engagement in conservation efforts. This integrated approach not only provides an understanding of coastal zone management but also serves as a valuable model for similar coastal regions worldwide.

8.2. Highlights

- This paper highlights the multidisciplinary approach of coastal resource management research using ten diverse indicators to determine the health of the coastal zone environment and six criteria to determine the susceptibility of the coastal zone environment to hazards.
- This paper addresses the limitations of the OHI.
    - The OHI framework introduced equal weighting to the ten diverse indicators, while this paper applied a flexible and adaptive expert-driven framework. The integrated CoZHI framework provides flexible weighting for each criterion, and the CoZHI framework is flexible to the challenges of the city.

    - The OHI determines the type of societal development of a certain city. These societal views are conservationist, extractive, non-extractive, and strongly extractive. Although the OHI determines the societal development of a city, there is no emphasis on which criteria should have greater weighting. Therefore, the CoZHI framework addresses this limitation. The flexibility of the weights can confirm the societal views of the city. For example, in this study, Mati City is a conservationist city; thus, natural products, fisheries, and biodiversity are the three most important indicators.
- This paper also accounts for the importance of hazards that can cause negative effects on coastal zone communities. Moreover, by integrating the CVA in the final CoZHI framework, a city can understand the importance of coastal hazards to the health of the coastal zone environment. This concept was not found in the study of OHI.
- This paper applied the AHP approach under multicriteria decision analysis. In the AHP, the respondents are experts. Thus, this paper implemented a purposive sampling approach in which the target respondents were planning officers, administrators, management officers, economists, city engineers, and academicians and researchers in the field of ecology and environment-related fields. This inclusion of expert respondents can provide recommendations regarding the design of the city's coastal zone management plan. The main reasons why the number of respondents is not important in this approach are the following:
    - Individual Expert Judgments. This approach relies on the judgments of individuals or a group of experts. The focus is on the quality and expertise of the judgments rather than the quantity of respondents. The method uses pairwise comparisons to establish priorities among a set of alternatives based on the decision maker's knowledge and experience.
    - Consistency of Judgment. This approach includes a mechanism for checking the consistency of the judgments made by respondents. This consistency test helps ensure that the judgments are logical and that the decision maker's preferences are consistent across different comparisons. Thus, having a consistent, reasoned set of judgments from even a single expert can be more valuable than inconsistent input from a larger group.

- Expert Knowledge. Knowledge is important in this study. The input from a few experts can be more relevant and appropriate than input from a large number of non-experts. The strength of the AHP lies in effectively leveraging expert insights.
- Composite and Aggregate Judgment. In cases where multiple respondents are involved, AHP can aggregate these individual judgments. These aggregated results focused on achieving a composite judgment that accurately reflects the group's overall preferences rather than simply increasing the sample size, as might be important in statistical surveys.
- Overall, in AHP, the depth and quality of the analytical process and the expertise of the respondents are more critical than the number of participants. This makes the method suitable for strategic decision-making where expert judgment plays a pivotal role.

- How does MCDA deal with significant tests? MCDA comprises a broad range of methods that assist in decision-making by evaluating multiple criteria. Traditional statistical significance tests are more commonly associated with statistical hypothesis testing rather than decision-making models in quantitative research. Some MCDA methods incorporate uncertainty and variability analyses that resemble significance testing in their approach. For example, the AHP addresses the inconsistency of the respondents by determining the CR. The robust analysis of the AHP in the CR evaluation shows how sensitive the final decision is to the changes in criteria weights. This analysis helps to understand the reliability of the chosen alternative under different assumptions, which can be related to the concept of "significance" of a result. To support this claim, the author published a paper to determine the sensitivity and validity of the weight of the criteria by changing the CR into three cases. The CR sensitivity was tested in three different CR scenarios: (1) the lowest CR was 2.0%, (2) the highest CR was 8.6%, and (3) the middle CR was 5.8%. The results illustrate that the ranking of classifications is the same in the three CR scenarios. The overall average change was only 0.02%. Therefore, changes in the CR value did not affect the results of the analysis as long as within the acceptable rate (Cabrera & Lee, 2019, Section 6). Thus, it shows the robustness and reliability of the analysis in utilizing the AHP- MCDA approach.

8.3. Implications of the integrated CoZHI assessment

- Policy and resource management. The CoZHI offers a clear quantitative indicator of coastal zone health. This can help to inform decisions about the conservation, management, and sustainable use of coastal and ocean resources. The CoZHI also recognizes gaps in the ten diverse indicators for improvement and helps prioritize initiatives. In an annual assessment, the city can track the progress of improvement in its respective coastal zone environment.
- Goals related to sustainability. The CoZHI is consistent with the global sustainability targets specified in the UN SDGs. Thus, it is an effective tool for tracking progress toward sustainability.
- Raise public awareness. The CoZHI is a tool to support and educate the public about coastal zone environment sustainability and conservation. The findings aware the public reflecting the effects of human activities on coastal and marine health.
- Research. The CoZHI inspires researchers to address the gaps. This can result in better data collection methods and insights into coastal zone health.
- Finance and funding. The CoZHI results can convince the government, NGOs, businessmen, and private sectors to pledge and commit funding for conservation to promote sustainable development where humans and the environment coexist.
- Benchmarking. The CoZHI enables city-level comparisons and serves as a standard for monitoring improvements in coastal zone health. This can help cities to collaborate in managing coastal and marine ecosystems.

8.4. Limitations and Future Work

This research covers a wide range of subjects, including the CoZHI, vulnerability assessments, and methodological techniques from ten different disciplines. It is safe to conclude that this research recognizes the complexity and challenges inherent in coastal zone management. The results of this research should be presented to the city council, offering suitable solutions for each criterion. Subsequently, the coastal zone health score should be reassessed annually to determine the changes based on the solutions provided by the previous results. Future research directions could include expanding the geographical scope of the study, refining the CoZHI framework based on additional empirical, observed, and experimental data, or exploring the impacts of emerging environmental and socioeconomic factors on coastal health and sustainability. Furthermore, data gathering should be improved by conducting primary data collection to supplement the deficiencies of the secondary datasets. Moreover, this study is multidimensional; each criterion has a different field of study; thus, an expert in this field should be the primary focal person to set the criterion methodology and interpret the results.

Another limitation of this study is the analysis of the relationships between CoZHI health index scores and potential predictor variables such as the Human Development Index (HDI), population, and gross domestic product (GDP). Further research may be needed to clarify how these factors specifically influence CoZHI scores and to establish more definitive causal relationships.

Appendix

Appendix A. Multicriteria Decision Analysis – AHP Tables

Table A1. Pairwise comparison matrix for Mati City.

Criteria	C	NE	E	SE
Conservationist (C)	1.00	6.00	7.00	8.00
Non-Extractive (NE)	0.17	1.00	2.00	4.00
Extractive (E)	0.14	0.50	1.00	4.00
Strongly Extractive (SE)	0.13	0.25	0.25	1.00
SUM	1.43	7.75	10.25	17.00

Table A2. Pairwise comparison matrix for Davao City.

Criteria	C	NE	E	SE
Conservationist (C)	1.00	4.00	3.00	7.00
Non-Extractive (NE)	0.25	1.00	1.00	4.00
Extractive (E)	0.33	1.00	1.00	6.00
Strongly Extractive (SE)	0.14	0.25	0.17	1.00
SUM	1.73	6.25	5.17	18.00

Table A3. Pairwise comparison matrix for Cagayan De Oro City.

Criteria	C	NE	E	SE
Conservationist (C)	1.00	2.00	2.00	3.00
Non-Extractive (NE)	0.50	1.00	0.50	3.00
Extractive (E)	0.50	2.00	1.00	5.00
Strongly Extractive (SE)	0.33	0.33	0.20	1.00
SUM	2.33	5.33	3.70	12.00

Table A4. Pairwise comparison matrix for Cebu City.

Criteria	C	NE	E	SE
Conservationist (C)	1.00	2.00	3.00	4.00
Non-Extractive (NE)	0.50	1.00	2.00	3.00
Extractive (E)	0.33	0.50	1.0	3.00
Strongly Extractive (SE)	0.25	0.33	0.33	1.00
SUM	2.08	3.83	6.33	11.00

Table A5. Pairwise comparison matrix for Puerto Princesa City.

Criteria	C	NE	E	SE
Conservationist (C)	1.00	2.00	3.00	2.00
Non-Extractive (NE)	0.50	1.00	2.00	2.00
Extractive (E)	0.33	0.50	1.00	1.00
Strongly Extractive (SE)	0.50	0.50	1.00	1.00
SUM	2.33	4.00	7.00	6.00

Table A6. Pairwise comparison matrix for Metro Manila City.

Criteria	C	NE	E	SE
Conservationist (C)	1.00	4.00	3.00	4.00
Non-Extractive (NE)	0.25	1.00	1.00	3.00
Extractive (E)	0.33	1.00	1.00	3.00
Strongly Extractive (SE)	0.25	0.33	0.33	1.00
SUM	1.83	6.33	5.33	11.00

Table A7. Pairwise comparison matrix for Laoag City.

Criteria	C	NE	E	SE
Conservationist (C)	1.00	3.00	2.00	4.00
Non-Extractive (NE)	0.33	1.00	2.00	3.00
Extractive (E)	0.50	0.50	1.00	4.00
Strongly Extractive (SE)	0.25	0.33	0.25	1.00
SUM	2.08	6.33	3.75	12.00

Appendix B. Sense of Place Questionnaire

Table A8. Study variables for the sense of place for tourists (Abou-Shouk et al., 2018)

Variable and Questions	1	2	3	4	5
Impressions • My first impressions of this place met my expectations. • This place is different from what I anticipated before arriving.					
Sense of Place • I felt a sense of welcome or belonging upon arriving. • Specific experiences or interactions during my visit moved or affected me deeply.					
Cultural Engagement • Participating in local cultural activities enhanced my understanding of this place. • Engaging with the local culture influenced my perception of this place positively.					
Environmental Perception • The physical environment here (e.g., landscape, architecture) is appealing. • There are unique features here that stand out as particularly beautiful.					
Social Interactions • My interactions with the locals have been positive. • Social interactions here have enhanced my experience of this place.					
Comparisons to Home • This place has qualities that are better than where I live. • There are aspects of this place that are worse compared to my home.					
Memorable Experiences • I have had experiences here that I would recommend to other tourists.					

• The most memorable parts of my visit are likely to influence my decision to return.					
Future Intentions • I would consider revisiting this place. • I would recommend this destination to friends or family.					

Table A9. Study variables for the sense of place for resident (Abou-Shouk et al., 2018)

Variable and Questions	**1**	**2**	**3**	**4**	**5**
Sense of Place • I feel deeply connected to this place. • I have formed significant relationships in this area.					
Identity and Place • I strongly identify with this place. • Living here influences how I describe myself to others.					
Memories and Experiences • My most vivid memories of this place are positive. • My experiences here have changed significantly over time.					
Perceptions of Physical Attributes • I find the physical landscape of this area appealing. • There are physical features of this place that I find particularly unappealing.					
Social Connections • The social interactions in this place significantly contribute to my sense of belonging.					
Community Involvement • I am actively involved in local community activities. • My involvement in the community strengthens my connection to this place.					
Future Aspirations • I see myself living here in the long term. • I desire specific changes to make this place better.					
Protection • I support local initiatives aimed at protecting the coastal environment • I participate in local community activities to clean and maintain the beautyiful environment					

Appendix C. Exposure to the changing coastal zone environment

One of the most important aspects of this assessment is to determine community exposure in the changing environment. This study evaluated the population exposure according to town (barangay), as shown in Figure 29 for Davao City and Figure 30 for Mati city. The built-up areas in Davao City are near the coastline, while the built-up areas in Mati city are located only in the city center. These ten (10) towns in Davao City are at least at high risk of coastal changes. These towns are Vicente Hizon Sr., Alejandra Navarro, Bunawan, Tibongco, Pamapanga, Lapu-Lapu, Centro, Dumoy, Lizada, and Binugao. Approximately 131,171 people are highly vulnerable to coastal changes, and 62,682 people are at a very high risk of coastal change. On the other hand, the 80,001 and 89,994 people in the population are at high and very high risk levels, respectively, in Mati city. Coastal barangays such as Dahican, Bobon, Tamisan, Lawigan, and Langka are at least at high risk of coastal changes.

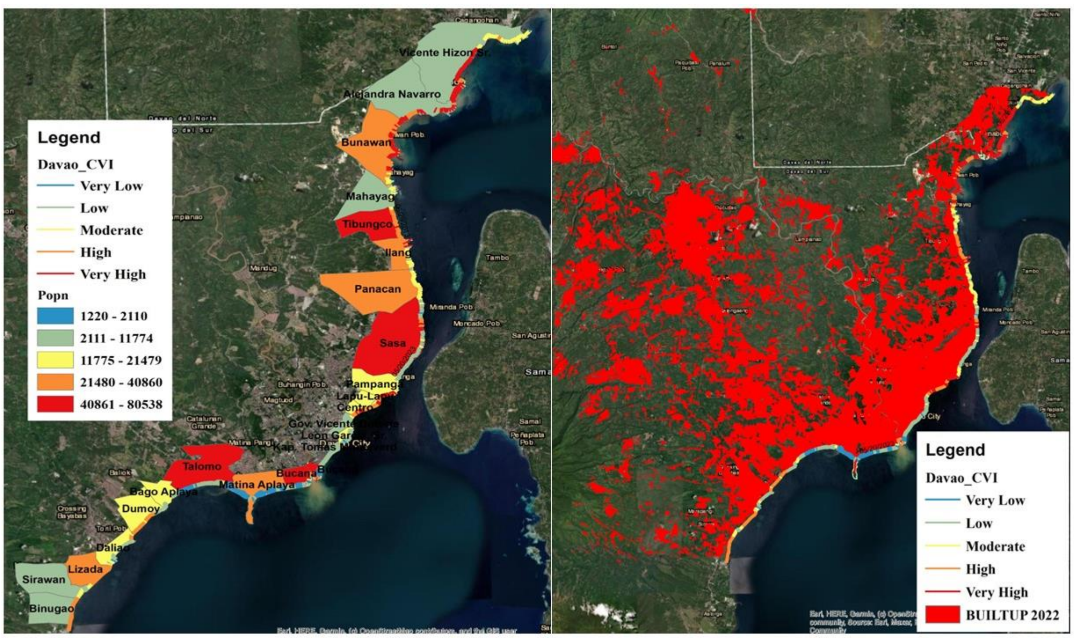

Figure 37. Exposure map of Davao City.

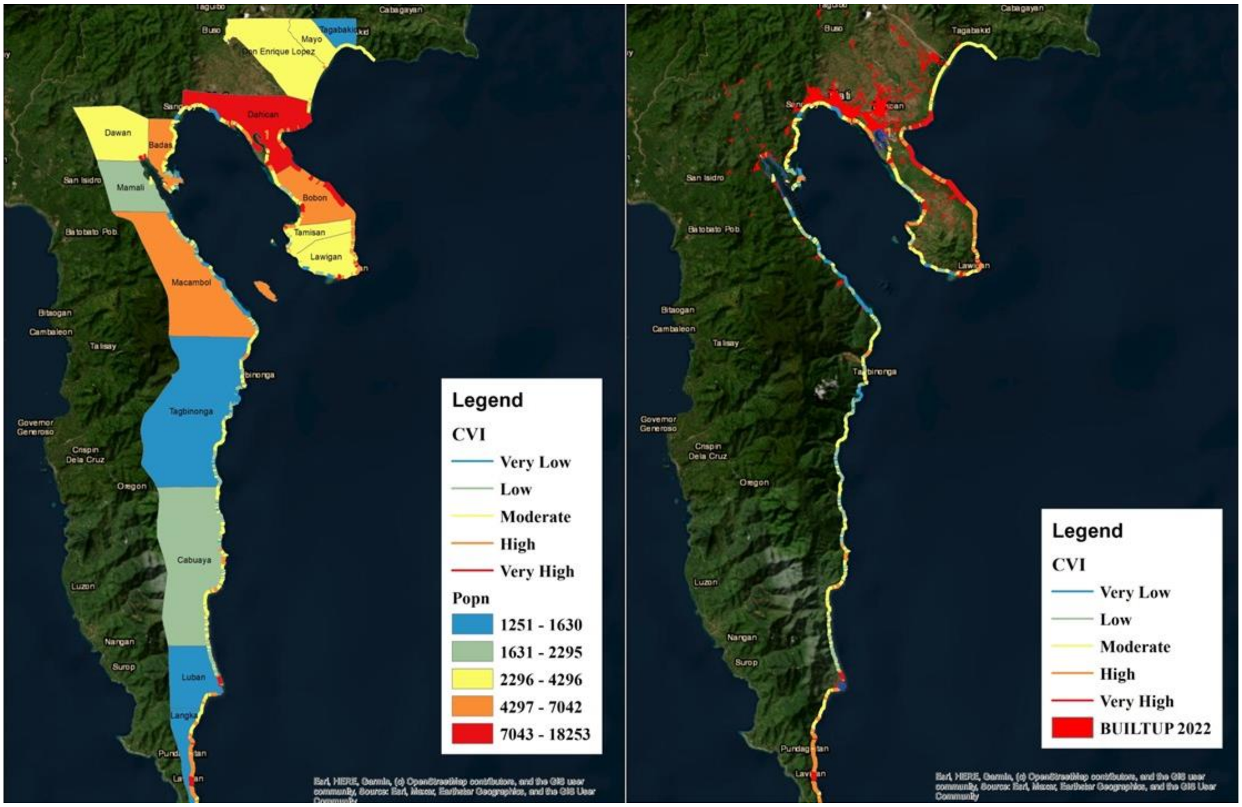

Figure 38. Exposure map of Mati City.

The social vulnerability assessment of the coastal towns in Mati City and Davao City was evaluated using the socio-economic vulnerability index (SEVI). There is a magnitude of definitions and interpretations of the socio-economic vulnerability assessment. The Intergovernmental Panel on Climate Change (IPCC) identifies three components of climate change vulnerability: exposure, sensitivity, and adaptive capacity (Sharma & Ravindranath, 2019). Furthermore, vulnerability is also a function of a system's resilience, which is the ability to absorb shock and recover after exposure to stress (Adger, 2006). Thus, this study focuses on the impact of the coastal zone's changing environment on the socioeconomic status of Mati and Davao City's coastal towns (barangay). This study aims to evaluate the vulnerability areas for seven socioeconomic sector groups using the PSA survey datasets as shown in Table C1. Also, establish the risk maps caused by SLR, Wave, and other physical characteristics of the coastal towns of Mati and Davao City. The definition of the socio-economic variables are shown below as defined by the literature and the PSA.

- Age is considered a critical demographic factor in assessing vulnerability as it can influence a household's or individual's ability to respond to and recover from climate-induced stresses. Different age groups may have varying degrees of resilience and vulnerability based on their physical capability, knowledge, and experience, as well as access to resources and social networks.

- Literacy refers to the ability to read and understand texts. Literacy enables individuals to engage with written content on climate science, policies, and adaptive strategies, making it a key factor in enhancing a community's or individual's capacity to adapt to and mitigate the impacts of changing climates.
- Marital Status can affect the social support structures available to individuals, influencing their adaptive capacity. For example, married couples may have a different set of resources and support systems compared to single individuals, which can affect their household's overall resilience to climate-induced stresses.
- Household Size plays a role in determining the level of vulnerability to climate change. Larger households might have more human resources to draw upon in times of need but may also face higher demands on their resources, including food, water, and economic resources, making them more susceptible to climate-induced stresses.
- Functional Difficulty:
    - Seeing refers to an individual using his/her eyes and vision capacity to perceive or observe what is happening around him/her.
        - Seeing things close up or far away, and
        - Seeing out of one eye or only seeing directly in front but not to the sides.
    - Hearing refers to an individual using his/her ears and auditory (or hearing) capacity to know what is being said to him/her or the sounds of activity, including the danger that is happening around him/her.
        - hearing in a noisy or quiet environment,
        - distinguishing sounds from different sources, and
        - hearing in one ear or both ears.
    - Walking or climbing steps refers to the use of lower limbs (legs) in such a way as to propel oneself over the ground to get from point A to point B. The capacity to walk should be without the assistance of any device (wheelchair, crutch, walker, and others) or human. If such assistance is needed, the person has difficulty walking.

    - walking short (about 100 yards/meters) or long distances (about 500 yards/meters),
    - walking any distance without stopping to rest is included, and
    - walking up or down steps.
  - Self-care refers to the capacity to take good care of him/herself. The capacity to cook, bathe, and dress should be without the assistance of any device or human. If such assistance is needed, the person has difficulty walking.

Table 44. Socioeconomic variables classification based on the PSA.

Variable	Low (1)	Moderate (2)	High (3)
Literacy (Chakraborty et al., 2020; Rajesh et al., 2018)	Literate		Illiterate
Average household size (Chakraborty et al., 2020)	3	4	>=5
Age (Chakraborty et al., 2020; Eidsvig et al., 2011)	18 – 30	31 – 60	1 – 17 & > 60
Marital status (Chakraborty et al., 2020)	Married / Live-in	Single	Divorced / Widow
Difficulty of Hearing (Chakraborty et al., 2020)	Without or with mild functional difficulty	With moderate functional difficulty	With severe functional difficulty
Difficulty of Seeing (Chakraborty et al., 2020)	Without or with mild functional difficulty	With moderate functional difficulty	With severe functional difficulty
Difficulty of Selfcare (Chakraborty et al., 2020)	Without or with mild functional difficulty	With moderate functional difficulty	With severe functional difficulty
Difficulty of Walking (Chakraborty et al., 2020)	Without or with mild functional difficulty	With moderate functional difficulty	With severe functional difficulty

The SEVI score calculation can be done using Equation 17 and 18. In the Equation 17, the $SEVI_i$ stands for the socio-economic vulnerability index for a specific category I, where (C1, C2, and C3) represents the counts of different calssifications of socioeconomic vulnerability as shown in Table A10, while the N is the sum of C1,C2, and C3. The Equation 18 is the overall socioeconomic vulnerability index score. It is the average of the seven individual values. The $SEVI_{1\ldots,7}$ represent the seven indices specified in Table A10. Each SEVI is calculated based on the specific criteria of low (1), moderate (2), and high (3) vulnerability classifications withn each category. The $SEVI_{score}$ is the overall socioeconomic vulnerability index score of a certain town (barangay), which is the average of the seven SEVI criteria.

$$SEVI_i = [C_1 + C_2 + C_3] / N \quad (17)$$

$$SEVI_{score} = [SEVI_1 + SEVI_2 + SEVI_3 + SEVI_4 + SEVI_5 + SEVI_{16} + SEVI_7]/7 \quad (18)$$

Figure A3 shows the normal distribution of population according to age and gender in the two cities. The distribution of the population is higher for both genders from young age through adolescence, while it decreases from age 30 to 75. This distribution exhibits a cone formation, which is typical for countries with increasing populations.

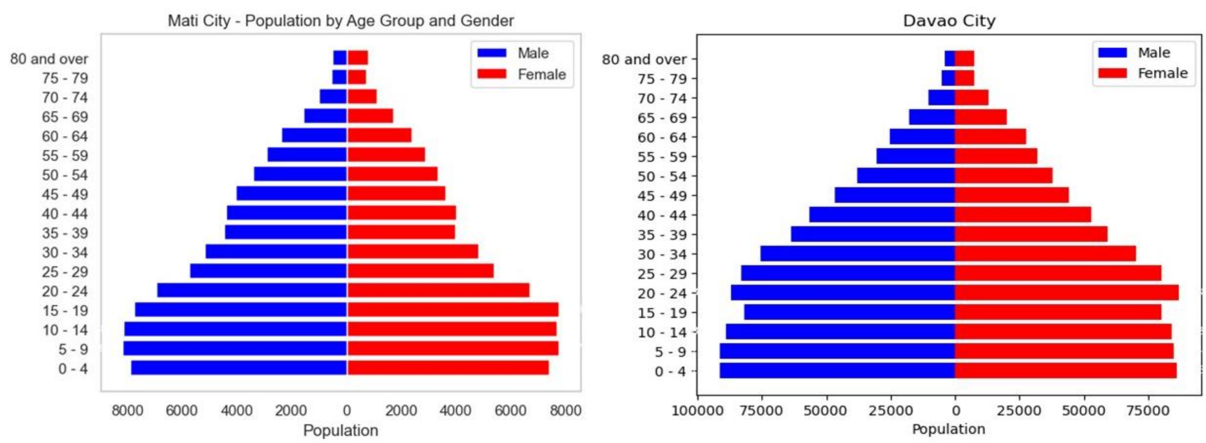

Figure 39. Population distribution by age group

Tables A11 and A12 show the socioeconomic distribution calculations for Mati City. In Mati City, the classification of age and marital status is moderate across all towns. This indicates that the population in these towns is moderately vulnerable to hazards based on these variables. Literacy is classified as low, indicating that most of the population in Mati City is highly literate. The difficulty variables (seeing, hearing, walking, and self-care) are also classified as low, meaning that Mati City has a smaller population with these difficulties. For the household size variable, six (6) towns have a moderate classification, while the rest have a high classification. This indicates that the average household size in almost every town is four or more, suggesting that larger household sizes are more vulnerable to hazards. The final SEVI score, seven (7) towns are classified as having low vulnerability to hazards, while eight (8) towns are classified as having moderate vulnerability.

Tables A13 and A14 show the socioeconomic distribution calculations for Mati City. The classification of age and marital status is moderate across all towns. This indicates that the population in these towns is moderately vulnerable to hazards based on these variables. Literacy is classified as low, indicating that most of the population in Davao City is highly literate. The difficulty variables (seeing, hearing, walking, and self-care) are also classified as low, meaning that Davao City has a smaller population with these difficulties. For the household size variable, six towns have a moderate classification, while the rest have a high classification. For the household size variable, two (2) towns are low, eleven (11) towns are moderate, while seven (7) towns are in the high classifications of vulnerability. There are small number of towns that are less vulnerable compare to Mati City. The final SEVI score, fourteen (14) towns are classified as having low vulnerable to hazards, while seven (7) towns are classified as having moderate vulnerability.

Table 45. Mati City socioeconomic distributions (Age, Marital Status, Household Size, Literacy).

Brgy	Age				Marital Status				Household Size				Literacy		
	L	M	H	Score	L	M	H	Score	Popn	#	Size	Score	L	H	Score
Bobon	873	1576	2608	2	2072	2715	270	2	5057	1098	5	3	4979	78	1
Badas	1130	2242	3670	2	2951	3835	256	2	7042	1587	4	2	6853	189	1
Cabuaya	307	621	1224	2	922	1169	61	2	2152	467	5	3	2079	73	1
Dahican	3232	5949	8932	2	7972	9326	814	2	18113	3746	5	3	17681	432	1
Dawan	576	1243	2127	2	1760	2004	182	2	3946	1025	4	2	3848	98	1
DEL	731	1372	2193	2	1903	2230	163	2	4296	931	5	3	4174	122	1
Langka	183	410	658	2	560	643	48	2	1251	297	4	2	1190	61	1
Lawigan	416	1029	1757	2	1309	1733	160	2	3202	710	5	3	3085	117	1
Luban	186	394	708	2	587	662	39	2	1288	283	5	3	1204	84	1
Macambol	729	1524	2699	2	2130	2585	237	2	4952	1082	5	3	4824	128	1
Mamali	356	748	1191	2	1022	1133	140	2	2295	561	4	2	2214	81	1
Mayo	510	1034	1717	2	1389	1708	164	2	3261	879	4	2	3154	107	1
Tagabakid	256	490	884	2	655	883	92	2	1630	454	4	2	1602	28	1
Tagbinunga	285	469	859	2	702	820	91	2	1613	344	5	3	1581	32	1
Tamisan	523	1169	1856	2	1537	1850	161	2	3548	701	5	3	3441	107	1

Table 46. Mati City socioeconomic distributions (Difficulties) including SEHI Score.

Brgy	Difficulty of Hearing				Difficulty of Seeing				Difficulty of Walking				Difficulty of Selfcare				Score	Remarks
	L	M	H	Score	L	M	H	Score	L	M	H	Score	L	M	H	Score		
Badas	6226	16	3	1	3034	15	2	1	6210	28	7	1	6232	4	9	1	1	L
Bobon	8894	21	4	1	2192	21	1	1	4505	15	11	1	4509	10	12	1	2	M
Cabuaya	9732	34	7	1	876	2	0	1	1865	9	3	1	1872	4	1	1	2	M
Dahican	3663	8	3	1	8099	12	6	1	16168	35	31	1	16196	12	26	1	1	L
Dawan	3540	14	2	1	1628	14	3	1	3532	17	7	1	3545	4	7	1	1	L
DEL	3797	6	3	1	1790	4	0	1	3796	4	6	1	3796	5	5	1	2	M

Langka	1118	1	2	1	524	0	0	1	1120	0	1	1	1119	0	2	1	1	L
Lawigan	2841	23	3	1	1327	25	3	1	2846	14	7	1	2842	9	16	1	2	M
Luban	1124	0	1	1	538	0	0	1	1124	0	1	1	1124	0	1	1	2	M
Macambol	4383	7	2	1	2062	3	1	1	4379	6	7	1	4381	5	6	1	2	M
Mamali	2081	7	3	1	981	6	0	1	4102	69	11	1	2079	7	5	1	1	L
Mayo	2909	4	1	1	1403	13	3	1	2898	11	5	1	2905	3	6	1	1	L
Tagabakid	1439	6	1	1	712	5	0	1	1437	4	5	1	1438	3	5	1	1	L
Tagbinunga	1427	2	2	1	637	0	1	1	1428	1	2	1	1426	1	4	1	2	M
Tamisan	3164	9	1	1	1535	12	2	1	3150	16	8	1	3163	4	7	1	2	M

Table 47. Davao City socioeconomic distributions (Age, Marital Status, Household Size, Literacy)

Brgy	Age				Marital Status				Household Size				Literacy		
	L	M	H	Score	L	M	H	Score	Popn	#	Size	Score	L	H	Score
Alejandra	1950	3941	5863	2	5178	5974	602	2	11754	2738	4	2	5147	100	1
Binugao	1551	2969	4121	2	4033	4187	421	2	8641	1876	5	3	3607	68	1
Bucana	15834	22452	34475	2	38377	38269	3879	2	72761	24558	3	1	35559	746	1
Bunawan	4189	7955	11929	2	10603	12354	1116	2	24073	5912	4	2	10117	197	1
Centro	3300	5728	7308	2	7571	7867	898	2	16336	3689	4	2	7263	126	1
Daliao	3764	7430	10285	2	9244	10920	1315	2	21479	5017	4	2	9445	143	1
Dumoy	3216	5830	8646	2	8645	9878	1113	2	17692	4525	4	3	8537	168	1
Duterte	1737	2599	3632	2	3630	3941	397	2	7968	2434	3	1	3540	30	1
Ilang	4508	8900	12742	2	11289	13689	1172	2	26150	5487	5	3	11111	244	1
Lapu-lapu	4508	8900	12742	2	5898	6689	557	2	26150	2945	9	3	5737	93	1
Garcia	2612	4260	6080	2	5486	6614	852	2	12952	3116	4	2	5537	82	1
Lizada	4331	7814	11505	2	10620	11947	1083	2	23650	4922	5	3	10102	216	1
Mahayag	1267	2335	3476	2	3355	3476	247	2	7078	1612	4	2	2924	48	1
Matina	6393	11318	14681	2	14724	16011	1657	2	32392	8411	4	2	14547	328	1
Monteverde	1100	1844	2314	2	2373	2573	312	2	5258	1453	4	2	2334	42	1
Pampanga	2901	4828	6507	2	7436	7429	751	2	14236	3337	4	2	6979	87	1
Panacan	6896	12267	17585	2	18496	20634	1730	2	36748	8958	4	2	17679	287	1
Sasa	9908	16078	23522	2	24740	27546	2521	2	49508	12131	4	2	23861	312	1
Sirawan	1447	2727	4084	2	3714	4137	407	2	8258	1755	5	3	3559	47	1
Tibungco	9230	16397	24000	2	21771	25540	2316	2	49627	10285	5	3	21210	403	1
VHS	2169	4199	4843	2	5274	5207	730	2	11211	2974	4	2	3540	30	1

Table 48. Davao City socioeconomic distributions (Difficulties) including SEHI Score.

Brgy	Difficulty of Hearing				Difficulty of Seeing				Difficulty of Walking				Difficulty of Selfcare				Score	Remarks
	L	M	H	Score	L	M	H	Score	L	M	H	Score	L	M	H	Score		
Alejandra	5209	436	5	1	5235	94	1	1	5210	44	14	1	5230	15	12	1	1	L
Binugao	3660	335	2	1	3668	51	3	1	3667	41	3	1	3672	14	2	1	2	M
Bucana	36178	1836	35	1	36252	280	23	1	3667	41	3	1	36179	101	58	1	1	L
Bunawan	10275	675	10	1	10295	114	6	1	10271	126	16	1	10281	22	19	1	1	L
Centro	7365	219	6	1	7378	34	7	1	7373	39	9	1	7381	12	6	1	1	L
Daliao	9520	605	6	1	9564	144	7	1	9550	146	16	1	9571	29	11	1	1	L
Dumoy	8680	503	6	1	8689	90	2	1	8677	98	10	1	8686	28	14	1	2	M
Duterte	3560	246	2	1	3561	18	3	1	3563	13	3	1	3566	8	3	1	1	L
Ilang	11325	516	7	1	11340	107	5	1	11325	102	9	1	11332	49	14	1	2	M
Lapu-lapu	5783	524	13	1	5813	49	12	1	5803	37	21	1	5806	20	19	1	2	M
Garcia	5571	385	7	1	5606	62	3	1	5599	42	9	1	5603	11	12	1	1	L

Lizada	10239	548	6	1	10280	119	4	1	10254	165	10	1	10295	26	14	1	2	M
Mahayag	2914	231	3	1	2957	54	2	1	2948	31	5	1	2956	11	8	1	1	L
Matina	14866	272	5	1	14868	48	3	1	14857	61	9	1	14867	36	6	1	1	L
Monteverde	2367	66	1	1	2369	25	1	1	2372	23	2	1	2373	4	3	1	1	L
Pampanga	7037	256	12	1	7039	36	17	1	7018	47	24	1	7028	14	26	1	1	L
Panacan	17895	1820	16	1	17939	228	8	1	17906	277	25	1	17920	51	24	1	1	L
Sasa	24114	766	29	1	24135	209	21	1	24082	209	44	1	24110	76	40	1	1	L
Sirawan	3585	165	4	1	3596	51	3	1	3588	39	7	1	3595	14	6	1	2	M
Tibungco	21457	1171	18	1	21554	216	21	1	21522	268	36	1	21564	66	38	1	2	M
VHS	5378	190	20	1	5383	69	18	1	5372	67	25	1	5374	18	29	1	1	L

Figure A4 depicts SEVI maps for Davao and Mati City. The blue and red colors indicate low and moderate vulnerability, respectively. Mati City has eight (8) towns that are moderately vulnerable. Interestingly, these towns have low income, smaller populations, but larger household sizes, indicating a higher vulnerability to changing hazards. The remaining towns are less vulnerable to hazards. On the other hand, Davao City has seven (7) towns that are moderately vulnerable. These towns also have larger household sizes. The rest of the towns in Davao City are less vulnerable to hazards.

Overall, the analysis heavily relies on the household size score. Although the difficulty variables are crucial, they do not significantly impact the final score. This suggests that household size is a key factor in determining vulnerability to hazards in these regions.

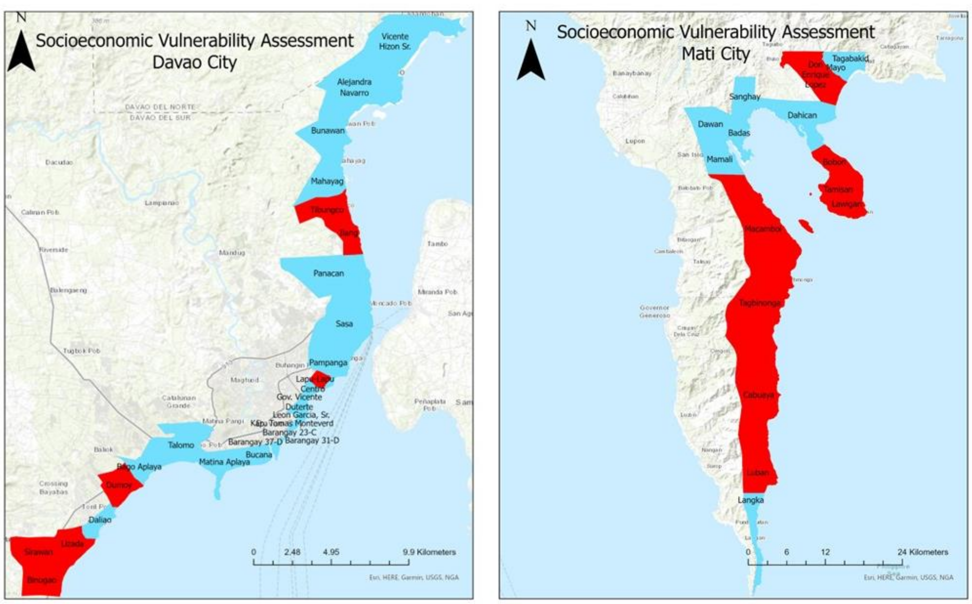

Figure A4. SEVI Map. Left: Davao City. Right: Mati City

Appendix D: Onsite Team Project

Coastal Zone Health Index Assessment for Sustainable Management: Part 2: Coastal Zone Vulnerability Assessment. Case studies for Davao and Mati City in the Philippines

I. Introduction

Coastal zones can be narrowly thought of as the interface between the sea and the land (Nelson, 2018). The geographical extent of the coastal zone includes areas within a landmark limit of 1 km from the shoreline at high tide and other areas within a seaward limit of 200 m in depth (Cabrera & Lee, 2022). These zones are important because most urban cities inhabit them. It has been estimated that 23% of the world's population lives within 100 km of coastal regions (Small & Nicholls, 2003).

Coastal zones offer a variety of significant ecological, social, and economic benefits. They are dynamic and diverse environments. They support a variety of human activities, such as fishing, tourism, and transportation, and are home to a wide range of plant and animal species.

However, there are a number of issues that coastal areas must address, such as pollution, climate change, and overdevelopment. The wellbeing and integrity of coastal ecosystems, as well as the communities and industries that depend on them, could be seriously harmed by these threats. It is crucial to routinely evaluate the health and wellbeing of these environments to address these issues and guarantee the long-term viability of coastal zones. The goal of this framework, known as coastal zone integrity assessment, is to identify any issues or problems that may affect the integrity of the coastal zone by gathering and analyzing data from a variety of sources.

There are a number of different approaches that can be used in a coastal zone integrity assessment, depending on the specific goals and needs of the assessment. For example, some assessments may focus more on the physical and chemical characteristics of the coast, such as water quality, sediment dynamics, and erosion rates. Others may be more focused on biological characteristics, such as the diversity and abundance of plant and animal species in the area.

In addition to these more scientific and technical aspects of coastal zone integrity assessment, it is also important to consider the social and economic factors that may impact coastal zones. This can include information such as land use patterns, population density, and the types of industries and activities that are taking place in the area.

The outcomes of the coastal zone integrity assessment can be used to guide the creation of policies and management strategies that will protect and enhance the integrity of the coastal zone after all the data have been gathered and analyzed. This could involve actions such as repairing damaged habitats, putting land use planning guidelines into practice, or creating protected areas.

Overall, assessing the integrity of the coastal zone is crucial for maintaining the many priceless resources and services that our coastal environments offer as well as for ensuring their long-term health and sustainability. It is crucial that we continue to make investments in this process and create cutting-edge strategies that can aid us in better comprehending and addressing the difficulties that our coastal zones face. Thus, the objectives of this study are as follows:

- Any issues or problems that may affect the health and well-being of the coastal environment were identified.
- Inform the development of policies and management strategies aimed at addressing and mitigating these threats to maintain or improve the overall health of the coastal zone.

- The potential vulnerabilities or weaknesses in coastal zones should be identified, and strategies for addressing these vulnerabilities should be developed.
- This study provides a comprehensive understanding of the current state of the coastal zone and can inform decision-making in a way that supports the long-term sustainability and health of the coastal environment.
- The government should invest in the process of assessing coastal zone integrity and develop innovative approaches to better understand and address the challenges facing coastal zones.

II. Methodology

1. Study Area

Davao City (see Figure 1) is a 1st class highly urbanized city in the southern part of the Philippines, with a total area of 2443.61 km^2. The city of Davao has the largest land area of all the cities in the Philippines. It is also the most populated city on Mindanao Island and the third most populous city in the Philippines. It has a population of 1,776,949 (PSA, 2020).

Mati city (see Figure 1) is a 5th class component city and the capital of the province of Davao Oriental, Philippines. It has a population of 147,547 (PSA, 2020). The city is surrounded by a beautiful mountain range on Mt. Hamiguitan, a UNESCO natural heritage site. This city is recognized by the Department of Environment and Natural Resources (DENR) as one of the most beautiful bays in the world with protected landscapes and seascapes.

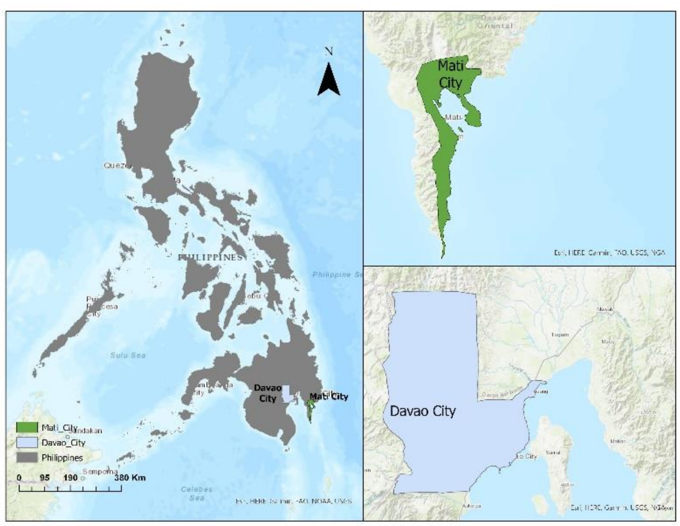

Figure 1. Map of the Philippines showing the locations of the two study areas (left). Mati city map (top-right). Davao City Map (Bottom-Right).

2. Datasets

The present study will use an index-based methodology applying the coastal vulnerability index (CVI) (Hastuti et al., 2022a). The information will be gathered from various sources to initially create a database of the parameters. Table 1 provides information on the data sources that will be used in this study.

Table 1. Sources and periods of the different usage parameters in the assessment.

Datasets	**Data source**	**Resolution**	**Period**
Geomorphology	Survey/Satellite image	-	2023
Shoreline Change Rate (m/year)	Landsat (earthexplorer.usgs.gov)	30 m	2012 and 2023
Elevation (m)	SRTM (https://dwtkns.com/srtm30m)	30 m	-
Sea level Change Rate (mm/year)	Tide Gauge (psmsl.com)	Monthly	2000-2023
Wave (m)	ERA5	Daily, /.5^0 x .5^0	2022
Sea Surface Temperature	ERA5	Daily, /.5^0 x .5^0	2022

The parameters will be ranked qualitatively according to the relative resistance of a given landform to erosion, while the values of the parameters will be assigned a vulnerability ranking based on the value ranges contributing to coastal vulnerability. Based on its potential to cause very low, low, moderate, high, and very high damage, for a specific area of the coastline, each parameter input is given an appropriate risk level (Table 2). The important factors are then combined into a single index and classified according to the relative severity of the risk to the coast. A flow chart of the methodology used to obtain the CVI maps of the two coastal cities is provided in Figure 2.

Table 2. Rating scale for the different parameters.

Parameters	**Very Low (1)**	**Low (2)**	**Moderate (3)**	**High (4)**	**Very High (5)**
Geomorphology (Nageswara Rao et al., 2008; Pendleton et al., 2010)	Rocky, Cliff coast, Fjords	Medium cliffs, Intended coasts	Low cliffs, Glacial drift, Alluvial plains	Cobble beaches, Estuary, Lagoon	Barrier beaches, Sand beaches, Saltmarsh, Mudflats, Deltas, Mangroves, Coral reefs
Shoreline Change Rate (m/year) (Hastuti et al., 2022a)	≥ 2.1 Accretion	1.0 to 2.0 Accretion	−1.0 to 1.0 Stable	−1.1 to −2.0 Erosion	≤−2.0 Erosion
Elevation (m) (Nageswara Rao et al., 2008)	≥ 30	20-30	10-20	5-10	0-5
Sea Level Change rate (mm/yr)	≤−1.1 Land rising	−1.0 to 0.99 Land rising	1.0 to 2.0 within range of eustatic rise	2.1 to 4.0 Land sinking	≥ 4.1 Land sinking
Wave (m)	< 2.00	2.00 - 3.00	3.00 – 4.00	4.00 - 5.00	>5.00

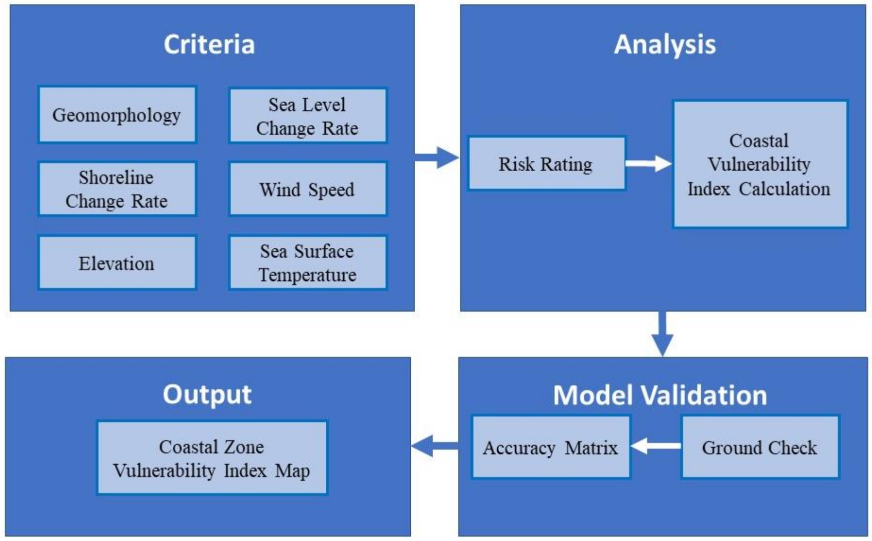

Figure 2. Framework to Obtain the Coastal Vulnerability Index Map

Different sources have different resolutions for the criteria. As a result, each parameter will be measured within a shoreline grid cell. This shoreline grid will be 1x1 km in size. The number of shoreline grids will be created, each with a unique identification number, and the vulnerability scale for each individual parameter will be assigned. This size will be considered adequate for uniform data scaling. Therefore, some data had to be up- or downscaled. This grid cell is widely used to evaluate coastal vulnerability (Bagdanavičiūtė et al., 2015; Islam et al., 2015; Koroglu et al., 2019; Rimba et al., 2018).

In this study, six parameters were considered for developing the CVI. These variables are geomorphology, shoreline change rate, elevation, sea level change rate, wind speed, and sea surface temperature. The importance of each parameter and the procedure for generating the values in the assessment CVI are given in the following section.

2.1. Geomorphology (G)

The process of creating a map that depicts the physical characteristics and features of a landscape is known as geomorphological mapping. This can include both man-made and natural features, such as roads, buildings, and other structures, as well as geographic features, such as rivers, valleys, hills, and coastlines.

Geological mapping is frequently used in numerous disciplines, including geology, environmental science, and civil engineering. The effects of human activity on the environment, as well as the natural processes such as erosion and sedimentation that shape the landscape, can be studied.

Geomorphological mapping can be carried out using a variety of methods, such as field observations, remote sensing, topographic maps, and aerial photographs. These methods can aid in presenting a thorough and accurate picture of a location's physical characteristics as well as in spotting any potential changes or trends over time.

Overall, geomorphological mapping is a crucial tool for obtaining an understanding of the landscape and assisting in the use and management of natural resources. This study can guide the development of strategies for reducing these risks by assisting in the identification of areas that may be vulnerable to natural disasters such as floods or landslides.

The surface type of a coastal area is referred to as coastal geomorphology. Different surface types in coastal areas react to coastal erosion in different ways. For instance, cliff coasts are less susceptible to erosion than sandy coasts. The geomorphology ranking in this study is based on the classification of Gornitz (1991), as shown in Table 2.

2.2. Shoreline Change Rate (SCR)

The shoreline changes rate gauges how quickly the shoreline of a body of water, such as a lake or the ocean, changes over time. It can be impacted by a variety of factors, including human activities such as building breakwaters or removing sand and gravel from the shoreline, as well as natural processes such as erosion and sedimentation. Shoreline changes can have a significant effect on the environment and coastal communities because they can result in habitat loss for animals and plants and jeopardize the stability of structures constructed close to water. The rate of shoreline change must be monitored by coastal managers to predict and mitigate potential effects.

The shoreline change rate is the rate at which the shoreline erodes or accumulates due to wave action, sea level rise, or other land-affecting hazards and processes. Using information from satellite imagery for the years 2013 (as a baseline condition) and 2023, the shoreline change rate was calculated (to describe the current conditions). The shoreline in 2013 and 2023 were compared at each grid cell along the shoreline to determine the rate of shoreline change. The rates of shoreline change are correlated with the categories of very low, low, moderate, high, and very high risk (Table 2).

2.3. Sea Level Change Rate (SLCR)

The rate at which the sea level changes over time is referred to as the sea level change rate. Numerous factors can affect this process, such as human activities such as the burning of fossil fuels and deforestation, as well as natural processes such as the melting of glaciers and thermal expansion. Since rising sea levels can result in flooding and the loss of coastal habitats, while falling sea levels can expose previously submerged areas, sea level change can have a significant impact on the environment and on coastal communities. To comprehend its causes and anticipate its future effects, scientists must focus on sea level change. Satellite measurements, tide gauges, and simulations of the ocean and its interactions with the Earth's climate system are some of the tools used to measure sea level change.

The Permanent Service of Mean Sea Level (PSMSL) (https://www.psmsl.com), in text file format, will be used to obtain the data on the mean sea-level rise. All of the monthly mean sea level data for all the stations in the study area between 2000 and 2023 were downloaded to calculate the sea level change rate and assign risk ratings.

2.4. Elevation (E)

Elevation is an essential factor to consider in vulnerability assessments of coastal areas because it can be used to detect areas that may be at risk of flooding or erosion due to sea level rise or storm surges. Coastal areas with higher elevations are generally considered less vulnerable to these types of impacts, as they are less likely to be inundated by rising water levels. On the other hand, low-elevation coastlines are more vulnerable to flooding and erosion and may be more susceptible to damage from these types of events. In addition to helping to identify vulnerable areas, elevation data can also be used to estimate the potential extent of land threatened by inundation and to identify the impacts of sea level rise on human populations and infrastructure.

The term digital elevation model (DEM) refers to a digital map that represents the surface of the earth and is derived from contour lines or photogrammetric techniques. The coastal elevation was obtained by processing the DEM data, and the elevation was categorized based on the determination of the vulnerability index, as shown in Table 2. Higher elevation coastal areas are thought to be less vulnerable because they are less likely to be flooded by storm surges or sea level rises. As a result, lower-elevation coastlines are extremely susceptible to erosion and flooding. The coastal elevation serves as a predictor of both the potential speed of shoreline retreat and the relative risk of inundation. To approximate coastal vulnerability, the coastal elevation must be measured along with the coastal morphology. In several CVI studies, the coastal elevation has been used to illustrate the vulnerability of coastal zone areas due to inundation, replacing the coastal slope that Gornitz (Gornitz, 1991) had previously used.

2.5. Wind speed (WS)

Wind speed is a significant factor to consider in coastal zone vulnerability assessments because it can have significant impacts on shorelines and coastal communities. High wind speeds can cause erosion of the shoreline, particularly if they are accompanied by large waves. Strong winds can also damage or destroy coastal structures such as buildings, roads, and bridges and can pose a hazard to people and animals in the affected area. In addition, strong winds can cause coastal flooding by pushing water onto land or by increasing the height of waves. This information can help coastal managers anticipate and plan for the potential impacts of high winds on shorelines and coastal communities.

2.6. Sea Surface Temperature (SST)

The sea surface temperature is an important factor to consider in coastal vulnerability assessments because it can have significant impacts on the physical and biological processes that occur in coastal zones. Changes in sea surface temperature can affect the distribution and abundance of marine species and can also impact the health of coral reefs and other coastal habitats. In addition, sea surface temperature can influence the intensity and frequency of storms and other extreme weather events, which can have direct and indirect impacts on the shoreline and coastal communities. When assessing the vulnerability of a coastal area, it is important to consider not only the current sea surface temperature but also the potential for future changes in temperature due to climate change or other factors. This information can help coastal managers anticipate and plan for the potential impacts of sea surface temperature changes onshore and coastal communities.

2.7. Coastal Zone Vulnerability Index Analysis

The CVI analysis will be conducted using the ArcGIS Pro GIS application, which creates and analyzes geospatial data. Once each section of the coastline has been assigned a risk value for each parameter, the key parameters are integrated into a single index via the CVI. The CVI is calculated as the square root of the product of the ranked parameters divided by the total number of parameters, as shown in Equation (1).

$$CVI = \sqrt{(SLCR + E + SST + WS + G + SCR)/6} \quad (1)$$

where SLCR is the risk rating assigned to the sea level change rate; E is the risk rating assigned to elevation; SST is the risk assigned to sea surface temperature; WS is the risk rating assigned to wind speed; G is the risk rating assigned to geomorphology; and finally, the SCR is the risk rating assigned to the shoreline change rate. The range of CVIs will be classified into four equal parts: quartiles or percentiles. The lowest range will be assigned low vulnerability, followed by moderate, high, and very high vulnerability.

III. Results and discussion

The current study will employ an index-based methodology, specifically coastal vulnerability assessment (CVA) (Hastuti et al., 2022b). The data were gathered from various sources to create an initial parameter database. Table 3 details the parameters used in this assessment. The parameter was qualitatively ranked based on the relative resistance of a given land formation to erosion, whereas the data values were assigned a vulnerability ranking based on value ranges contributing to coastal vulnerability. Each parameter input is assigned an appropriate risk level based on its potential to cause very low, low, moderate, high, and very high damage to a specific area of the coastline (Table 4). The significant factors are combined into a single index using Equation 6 and classified based on their relative values.

3.1. Geomorphological assessment

Figure 3 shows the geomorphology of the city of Davao and Mati. The coastal areas of Davao City have a geomorphic classification of one, accounting for approximately 45% of the total records. Classification 1 denotes rocky, cliff-side, and man-made structures. This is because the city is currently constructing coastal roads and seawalls. In addition, approximately 30% of coastal areas are classified as type 5: sand beach, salt marsh, mudflats, and deltas. Mati city, on the other hand, is a predominantly low cliff and plain, approximately 45%, followed by 23% and 22% of class 4 (i.e., cobble beach, estuary, and lagoon) and 5 (i.e., sand beach, saltmarsh, mudflat, and coral areas), respectively.

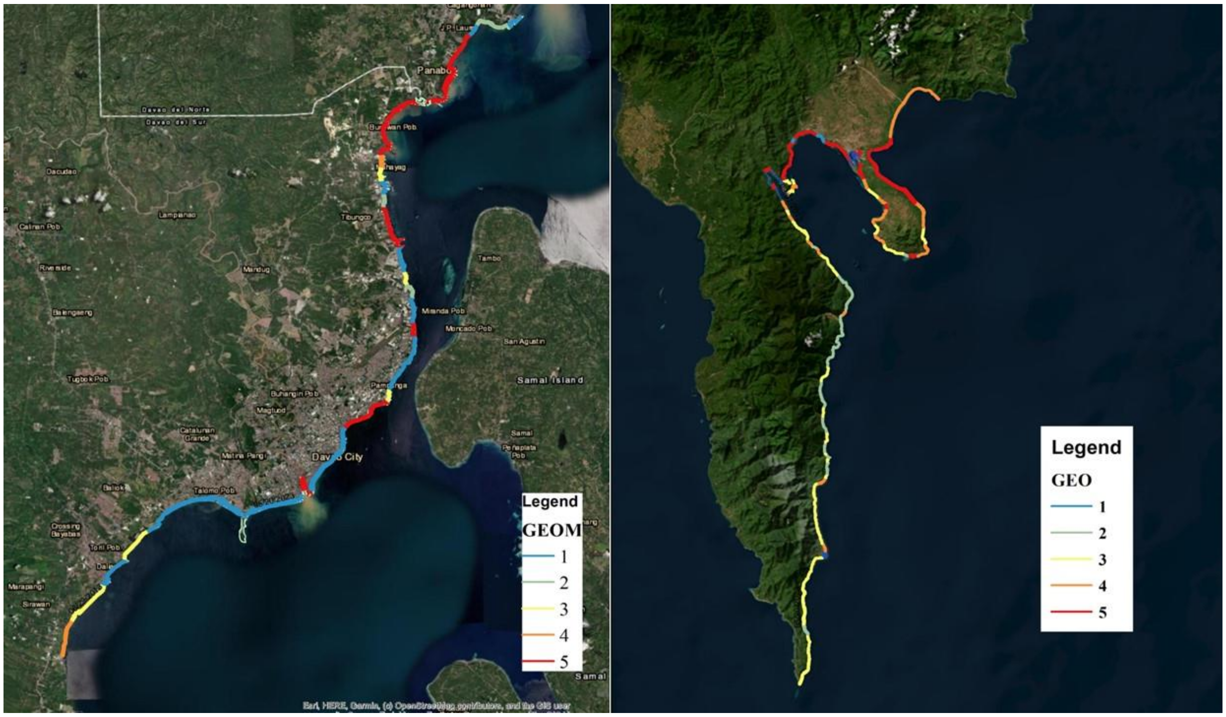

Figure 3. Geomorphology assessment of Davao (left) and Mati City (right).

3.2. Elevation assessment

Figure 4 depicts the coastal elevations of both cities. Low-elevation coastlines are more vulnerable to coastal flooding and erosion and may sustain more damage as a result of these events. At the same time, plants at higher elevations are thought to be more resistant to such impacts. Furthermore, it is less likely to be inundated as sea levels rise. One-third (33%) of Davao City's areas are slightly elevated, ranging from 5 to 20 meters. Unfortunately, 66% are classified as 5, which means they have an elevation of less than 5 meters. These regions are susceptible to SLR, storm surges, and other coastal hazards.

The majority of the coastal areas of Mati city are between 5 and 10 meters in elevation, accounting for approximately 48%, with 41% of coastal elevations falling between 5 and 10 meters. Only a small percentage of the area (7%) is extremely close to sea level. Additionally, a minor segment (4%) falls under the second classification, which ranges from 20 to 30 meters. These are low cliff areas at the foot of Mt. Hamiguitan.

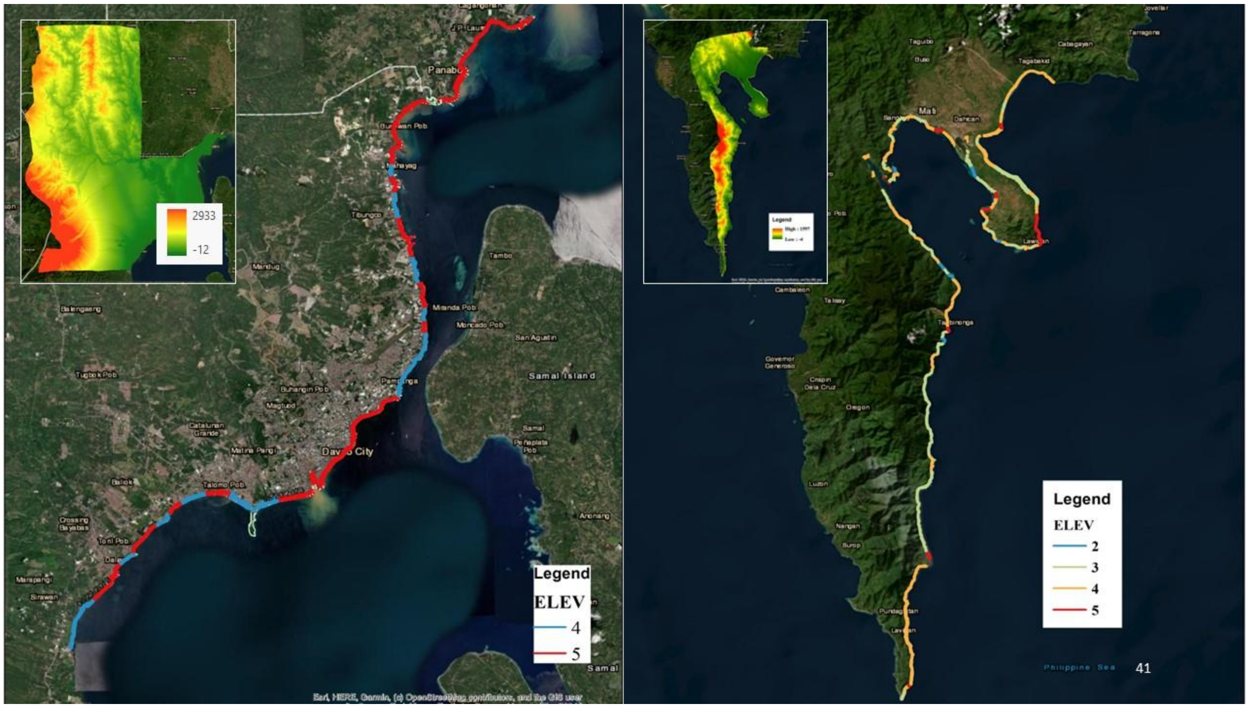

Figure 4. Elevation assessment of Davao (left) and Mati city (right).

3.3. Sea surface temperature assessment

Figure 5 depicts the sea surface temperatures for the two study cities. Sea surface temperature is an important factor to consider in coastal vulnerability assessments because it has a significant impact on physical and biological processes in the coastal environment. Furthermore, variations in sea surface temperature can have an impact on the distribution and abundance of marine species, as well as the health of coral reefs and other coastal habitats. Furthermore, it has the potential to influence the intensity and frequency of storms and other extreme weather events, which can have both direct and indirect effects on the shoreline and coastal communities. The SSTs in Davao and Mati city have been consistently classified as Class 3 for the past ten years, indicating a temperature range of 29-30°C. This indicates that the observed SSTs for all the locations in the coastal zone fall within the 29-30°C range. Such consistently warm sea surface temperatures can have implications for various marine and coastal processes, including coral reef health, evaporation rates, and potential influences on local weather patterns.

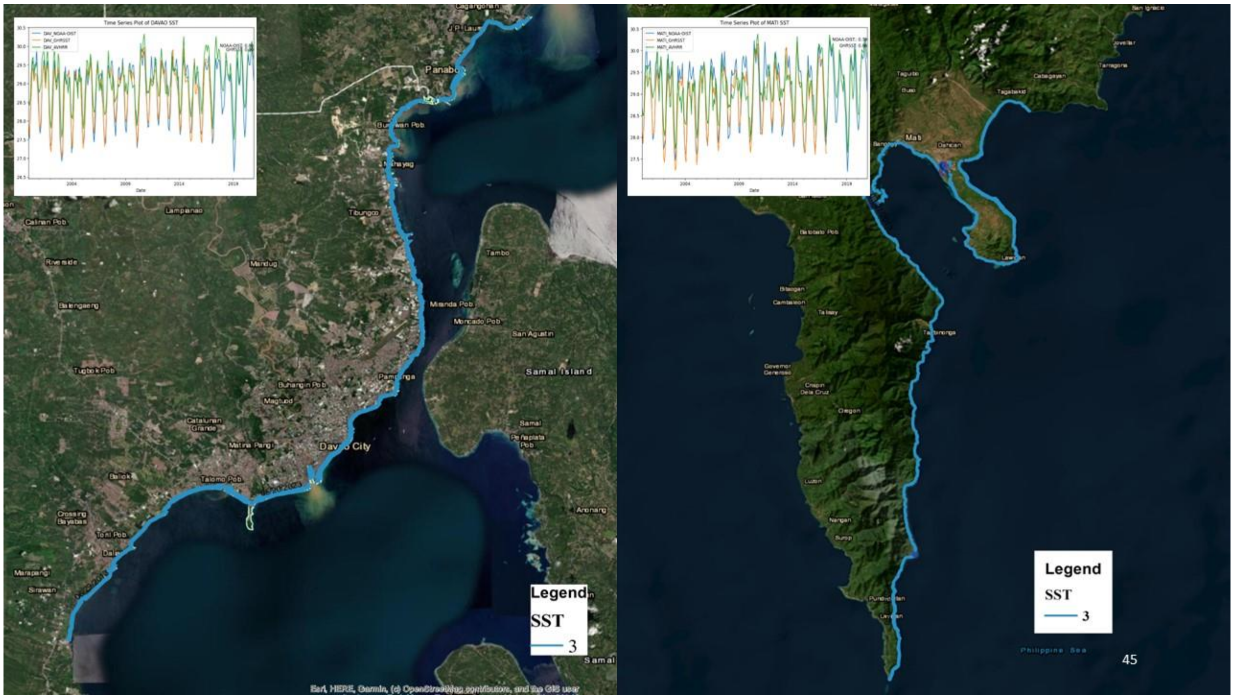

Figure 5. Sea surface temperature assessment of Davao (left) and Mati city (right).

3.4. Wave assessment

Figure 6 describes the wave assessment of Davao and Mati city. This paper utilized the significant wave height (SWH) from ERA5. The SWH is the average height (trough to crest) of the highest one-third of waves within 12 h. As wave energy increases, the mobilization and transport of coastal material also increases. Coastal areas with higher significant wave heights are considered more vulnerable than coastal areas with lower significant wave heights (Hastuti et al., 2022b).

The dataset consistently measures the SWH for Davao City's coastline, with all values falling under SWH Class 1 (0.39 m). This uniform classification spans the 77 km coastline, indicating a consistent wave height measure across the city's coastal areas. In the coastal zone of Mati city, the SWH data reveals a varied distribution of wave conditions. Most of the observations, approximately 39.21%, experienced wave heights within the range of 0.85 to 1.05 meters. Approximately 38.30% of the areas encounter waves falling within the 0.55 to 0.85 m range. A smaller fraction of the dataset, approximately 22.49%, shows calmer conditions with wave heights below 0.55 meters. This distribution indicates that during the observed period, most parts of the coastal region of Mati city experienced moderate wave heights, ranging between 0.55 and 1.05 meters.

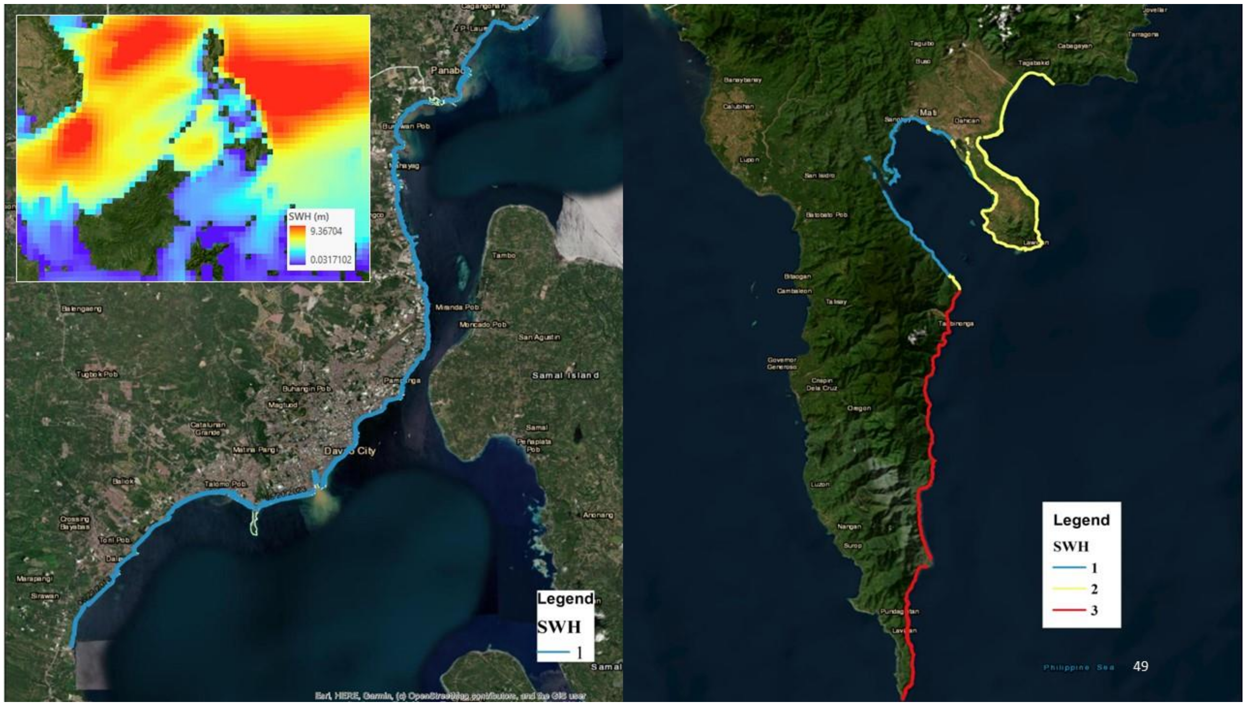

Figure 6. Significant wave height assessment of Davao (left) and Mati city (right).

3.5. Shoreline change rate assessment

Figure 7 and Table 3 show the shoreline change rates in the two cities. Figure 14 displays the spatial distribution, while Table 26 depicts the percentage contribution according to the classes. Classification 4, which is a negative accretion ranging from -1.1 to -2.0, is the significant portion of the coastline in Davao City at 42.76 km (55.54%), followed by the 3rd class (i.e., -1 to 1), with approximately 19% of the coastline. Areas in the 4th class indicate a very dynamic shoreline. Given their extensive stretch and high rate of change, these regions demand urgent and continuous monitoring coupled with proactive interventions. These areas may require mitigation strategies or reinforcements to manage the changing shoreline effectively. Overall, the SCR classification clearly revealed the dynamic coastline of Davao City. With over half of the coastline (SCR Class 4) undergoing significant changes, there is an urgent need for comprehensive monitoring and proactive interventions.

In Mati city, the 2nd class was the most prominent, representing approximately 50.32% of the coastline. This translates to an estimated length of 95.11 km, followed by the 3rd, 4th, 1st, and

5th classes with lengths of approximately 19% (36.28 km), 14 (23.23 km), 11% (20.59 km), and 6% (10.79 km), respectively. The entire coastline of Mati city spans 189 km, which is at least low in terms of the changes in the shoreline due to the geomorphic types of the coastal areas.

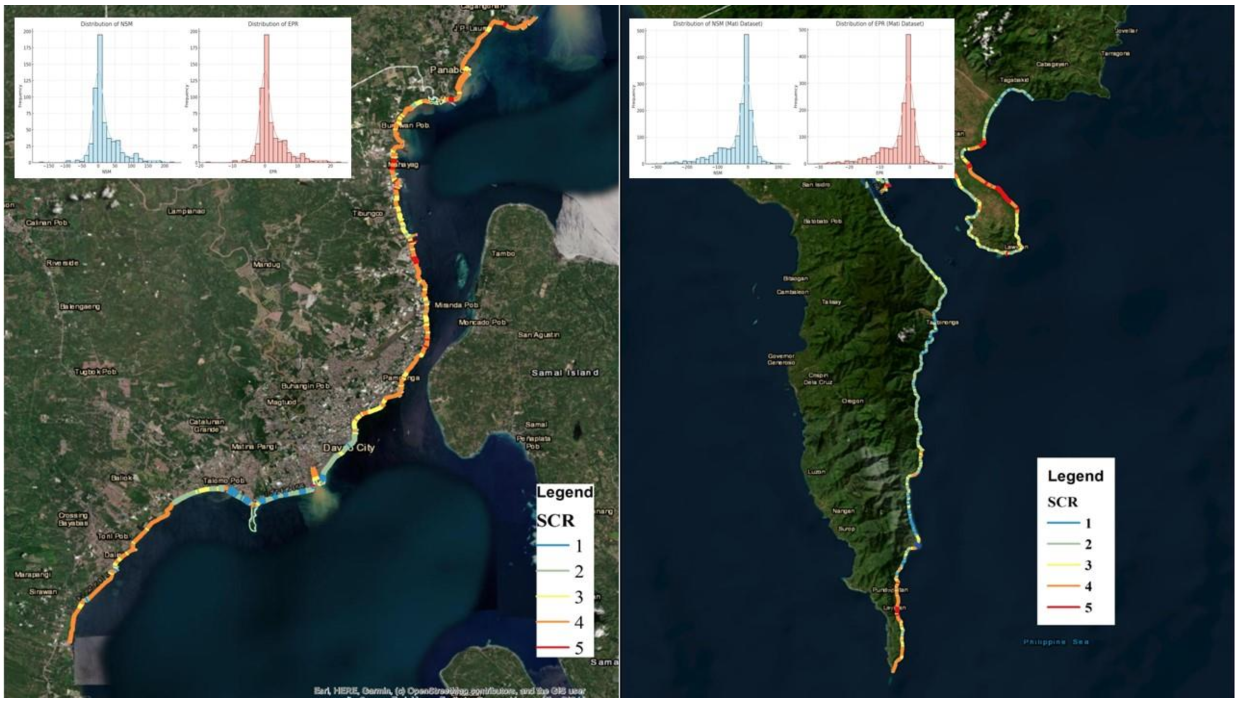

Figure 7. Shoreline coastal rate assessment for Davao City (left) and Mati city (right).

Table 3. Shoreline change rate for the two cities.

Class	Length (km)		Percentage (%)	
	Davao	Mati	Davao	Mati
1 (>= 2.1)	4.98	20.59	6.47	10.89
2 (1 to 2)	11.81	95.11	15.33	50.32
3 (-1 to 1)	14.69	36.28	19.08	19.20
4 (-1.1. to -2.0)	42.76	26.23	55.54	13.88
5 (<= -2.0)	3.58	10.79	2.75	5.71

3.6. Sea level change rate assessment

Table 4 shows the locations of all available tide gauges in the Philippines. There are 28 stations in the Philippines and one station each in the study area (Davao and Mati city). The sea level of the Philippines has reached approximately 4.9 ± 2.27 mm/year over the last two decades. Even though this increase is high compared to the global sea level rise, which is 3.5 ± 0.36 mm/year (Cabrera et al. (2024), unpublished), there is a variation in the rate of sea level due to the archipelagic nature of the Philippines. Figures 8 and 9 show the results of the ICEEMDAN model for Davao City and Mati city. In the first decade (i.e., 2000-2010), the trend of sea level rise in Davao City was fortunate; in 2011, the SLR decreased, but it gradually returned to an increasing trend. The sea level rate in Davao City is 0.8 ± 0.02 mm/year. The risk classification of Davao City is 1. Figure 8 shows the results of the ICEEMDAN algorithm. The risk in Mati city sharply increased at approximately 15.4 ± 7.00 mm/year, with a risk classification of 5. This is due to the location of the city facing the Pacific Ocean. Additionally, the rate was triggered by several earthquakes that occurred in this city. Recent large earthquakes of magnitude 6.1 occurred on March 2024, and multiple severe earthquakes occurred in recent decades. Furthermore, this city is connected to the Philippine faultline from Luzon Island down to Mindanao to Mati city.

Table 4. Tide gauge stations in the Philippines.

Location	Station ID	Latitude	Longitude
San Fernando, La Union	548	16.617	120.3
San Jose	1711	12.333	121.083
Port Irene	1705	18.383	122.1
Caticlan Malay, Aklan	2172	11.95	121.933
Pulupandan, Negros Occidental	2151	10.517	122.8
Currimao, Ilocos Norte	2173	17.983	120.483
Balanacan, Marinduque	2157	13.533	121.867
Subic, Zambales	2176	14.767	120.25
S. Harbor, Manila	145	14.583	120.967
Legaspi, Albay	522	13.15	123.75
Virac, Catanduanes	2150	13.583	124.233
Real Quezon	2035	14.667	121.6
Tacloban, leyte	664	11.25	125
Cebu	394	10.3	123.917
Balintang, Quezon, Palawan	2155	9.35	118.133
Puerto Princesa, palawan	207	9.75	118.733
Mati, Davao Oriental	2156	6.95	126.217
Davao, Davao City	537	7.083	125.633
Pagadian City	2152	7.817	123.433
Makar, General Santos City	2153	6.1	125.15
Zamboanga City	2175	6.917	122.067
Jolo, Sulu	260	6.067	121
Macabalan Port, Cagayan de Oro	2154	8.5	124.667
Tandag, Surigao del Sur	2158	9.083	126.2
Mambajao, Camiguin	2174	9.25	124.733
Surigao	1708	9.783	125.5

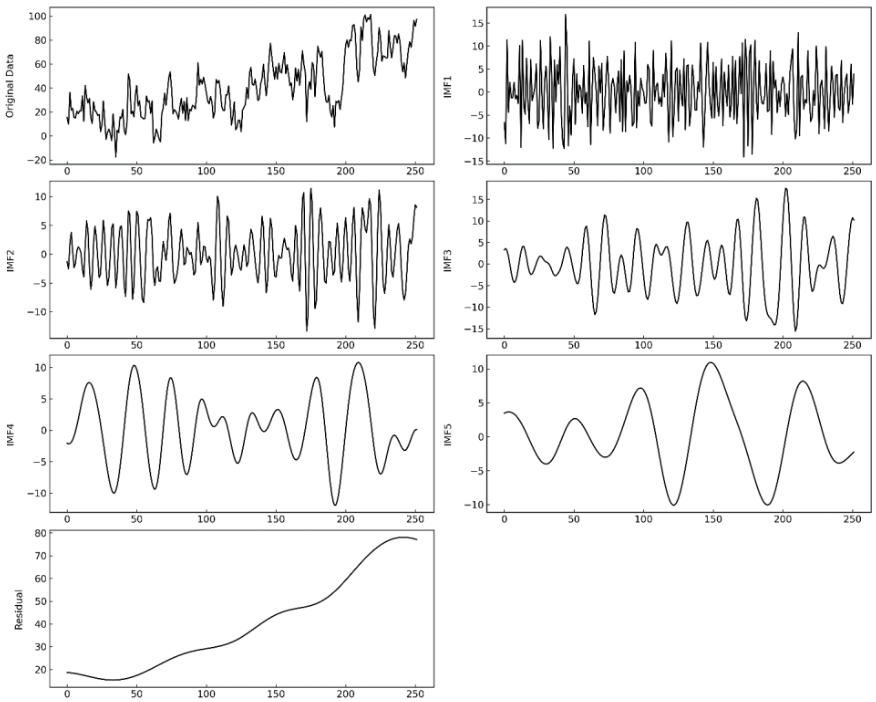

Figure 8. Davao City MSL fluctuation. The original data are shown, followed by the 6 IMFs from high to low frequencies. At the bottom right is the trend obtained using ICEEMDAN

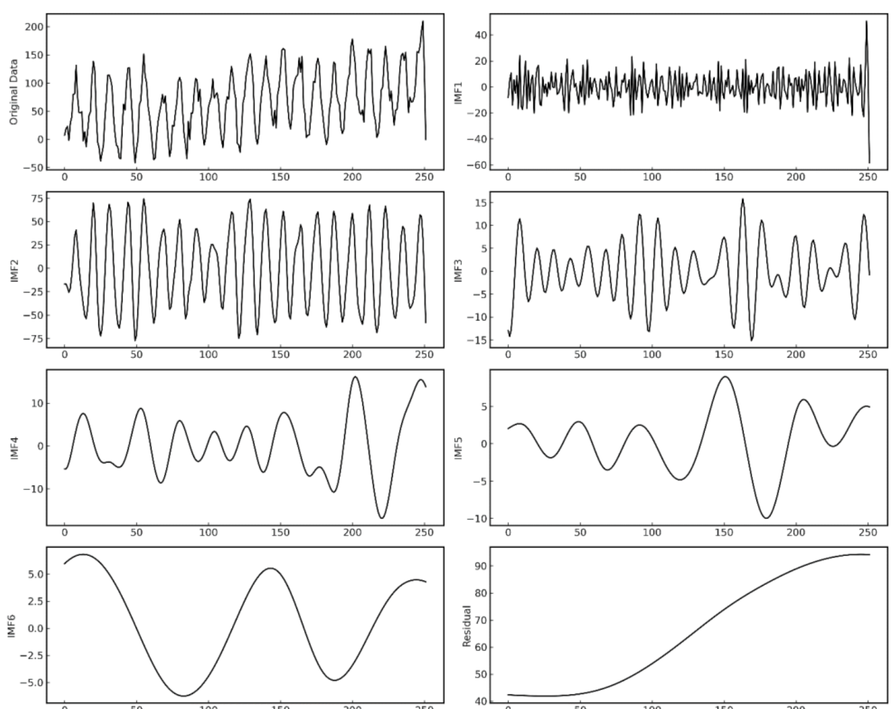

Figure 9. The MSL fluctuations in Mati city. The original data are shown, followed by the 4 IMFs from high to low frequencies. At the bottom right is the trend obtained using ICEEMDAN

5.7. Coastal zone vulnerability assessment score

Figure 10 displays the spatial distributions of the CVAs of Davao City (left) and Mati city (right). Table 5 illustrates the percentage of each class in the CVA assessment of the two cities. The CVA combines six (6) factors: the SLR, elevation, geomorphology, SCR, SLCR, SWH, and SST. The CVA has five classes. A very low vulnerability represents the lowest vulnerability, followed by low, moderate, high, and very high vulnerability. The very high vulnerability signifies the highest vulnerability in the coastal areas of the two cities. The accuracy of the CVA in these two cities is acceptable, with accuracy rates of 80.07% and 88.24%, respectively. The CVA scores of Mati city and Davao City were 1.62 and 1.63, respectively, indicating low vulnerability to the changing coastal environment.

The majority of the coastline of Mati city has a moderate CVA of 58%, which signifies a substantial portion of the coast of Mati city, approximately 109 km. The areas under Classes 4 and 5, approximately 32.3% of the coastline, indicate regions of greater vulnerability. These areas are sand beaches with low elevations facing the Pacific Ocean, as shown in the figure. These areas need immediate attention, conservation efforts, or infrastructure development to handle potential threats. Classes 1 and 2, representing a smaller portion of the coast (~10%), should be noted. Continuous monitoring can ensure that these areas do not transition to higher vulnerability classes.

The majority of the coastal areas in Davao City have moderate to high CVAs, with values of approximately 25.21% (19,41 km) and 32.54% (25.05 km), respectively. These two levels are areas under critical vulnerability. A very high CVA should be considered since it covers 20% of the coastline and is a critically vulnerable area. These zones require immediate interventions to mitigate potential adverse impacts.

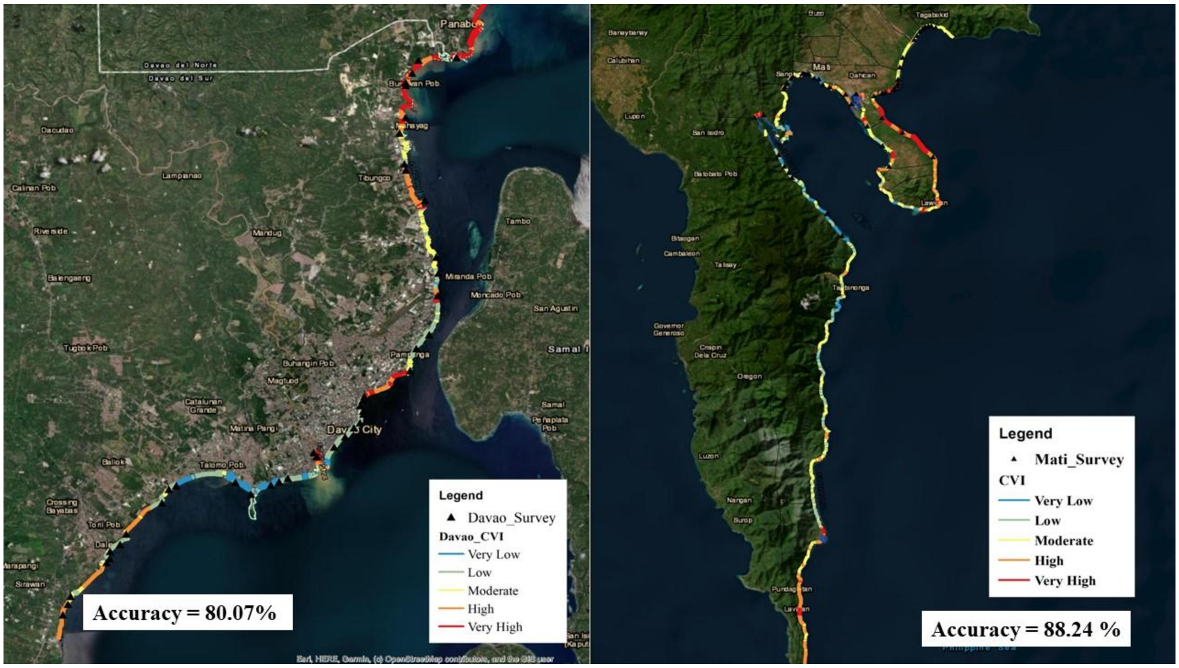

Figure 10. Coastal vulnerability index results for Davao City (left) and Mati city (right).

Table 5. Coastal vulnerability assessment for the two cities.

Class	Length (km)		Percentage (%)	
	Davao	Mati	Davao	Mati
Very Low	7.74	1.59	10.05	0.84
Low	9.71	16.67	12.61	8.82
Moderate	19.41	109.70	25.21	58.04
High	25.05	43.39	32.54	22.96
Very High	15.09	17.65	19.59	9.34

5.8. Exposure to the changing coastal zone environment

One of the most important aspects of this assessment is to determine community exposure in the changing environment. This study evaluated the population exposure according to town (barangay), as shown in Figure 11 for Davao City and Figure 12 for Mati city. The built-up areas in Davao City are near the coastline, while the built-up areas in Mati city are located only in the city center. These ten (10) towns in Davao City are at least at high risk of coastal changes. These towns are Vicente Hizon Sr., Alejandra Navarro, Bunawan, Tibongco, Pamapanga, Lapu-Lapu, Centro, Dumoy, Lizada, and Binugao. Approximately 131,171 people are highly vulnerable to coastal changes, and 62,682 people are at a very high risk of coastal change. On the other hand, 80,001 and 89,994 people in the population are at high and very high-risk levels, respectively, in

Mati city. Coastal barangays such as Dahican, Bobon, Tamisan, Lawigan, and Langka are at least at high risk of coastal changes.

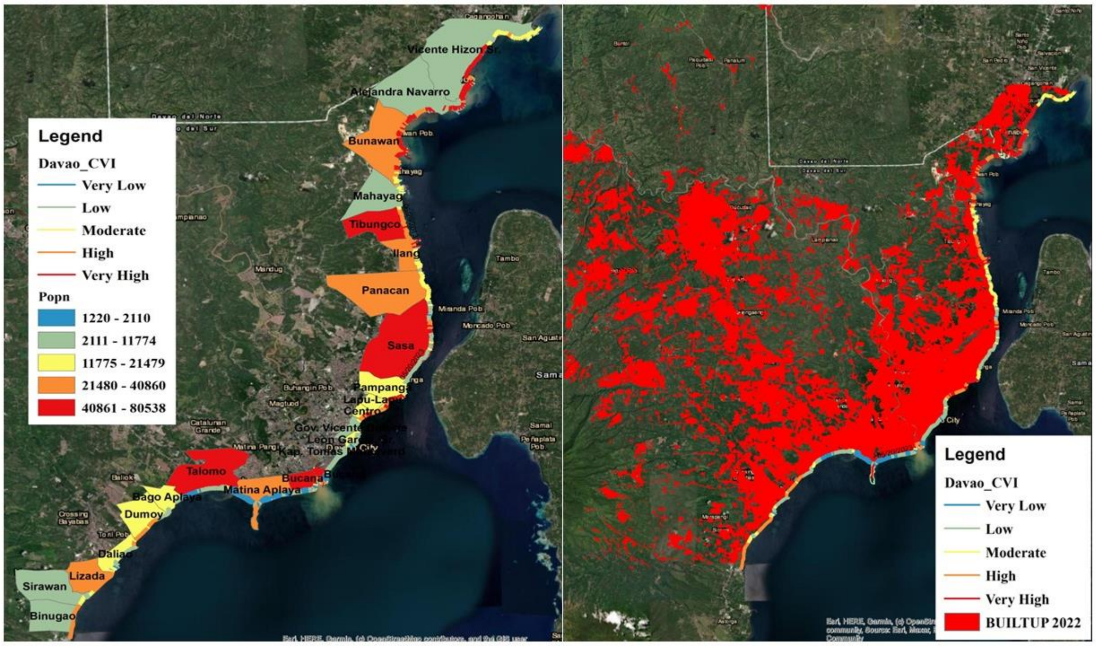

Figure 11. Exposure map of Davao City.

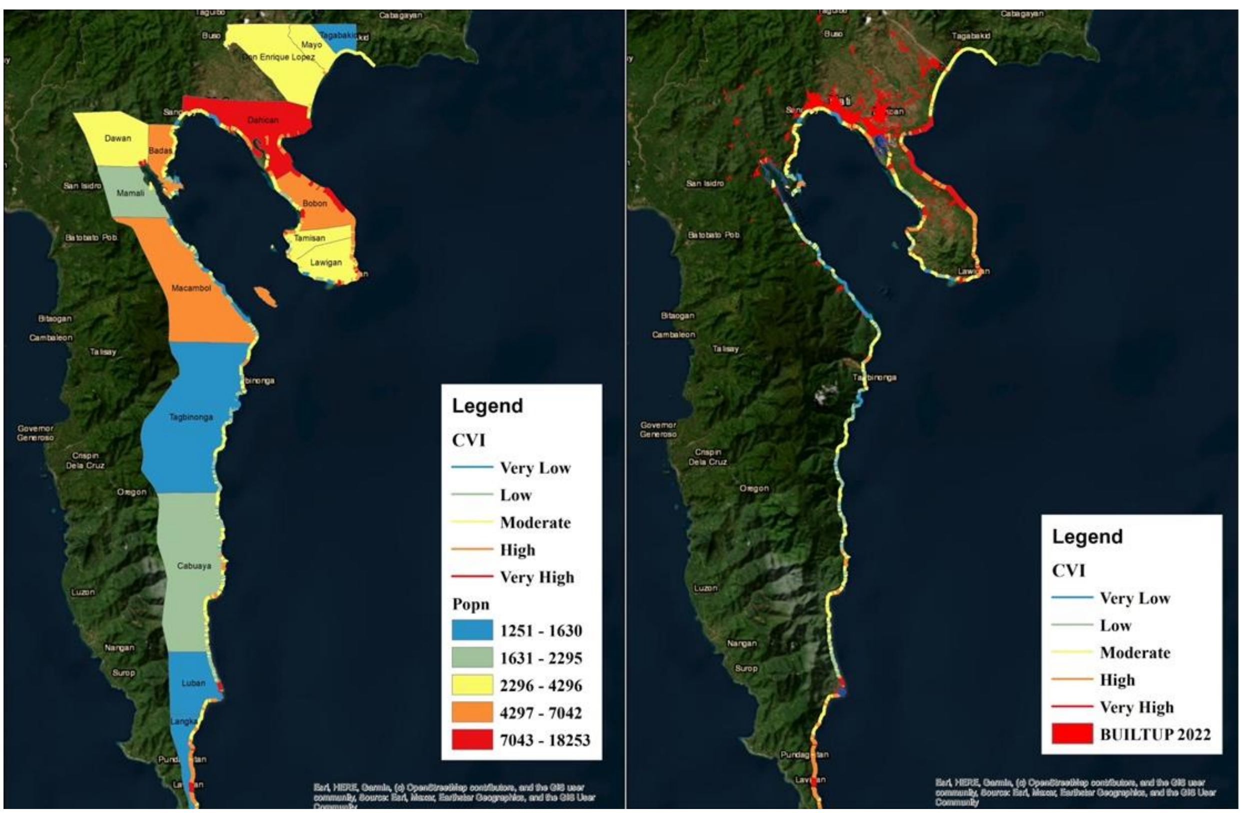

Figure 12. Exposure map of Mati city.

The coastal vulnerability assessment was performed by CVA analysis using GIS and remote sensing technologies to measure the risk level of coastal areas in Mati and Davao City efficiently and appropriately, considering both geological and physical parameters. This study showed that geomorphology, shoreline change rate, and coastal elevation are the parameters that most contribute to determining coastal vulnerability since the sea level change rate was given the same risk level along the coast. The parameter with the greatest contribution could be further improved using weighted determination. In addition, the proposed index is feasible for assessing coastal vulnerability in other coastal areas when dealing with climate change.

Although some places are at high risk, Mati and Davao City have CVA values of 1.62 and 1.63, respectively. The CVA map created for Mati and Davao City is useful for decision-makers in disaster mitigation and management. It aids efforts to reduce the effects of climate change. However, the study has shortcomings. The emphasis on remote sensing and GIS may not capture local variations that influence vulnerability assessments. Furthermore, assigning risk levels uniformly throughout coastal sections may influence the complex interaction of factors impacting coastal vulnerability. This can lead to underestimation or overestimation in some places.

Outputs:

1. Training Workshop on Coastal Zone Vulnerability Assessment – April 3-5, 2023 at Davao Oriental State University, Philippines
   Program:

Time	Activity	Speakers/Presenters
Day 1 (April 3)		
8:00-8:30	Welcome Remarks	SUC President III, Dr. Roy G. Ponce
	Overview and introduction of participants - DOrSU researchers - Provincial/City environment and natural resources selected personnel.	
8:30-9:30	Introduction of TAOYAKA Onsite Project and Coastal Hazards and Energy System Science	Mr. Jonathan Cabrera Prof. (Dr. Eng) Han Soo Lee
9:30-10:00	Coffee Break	
10 – 12:00	Basic Training of GIS - Study area map design - Develop grid/administrative boundary assessment map guide. - Survey result integration in the GIS. - Plot the result	Mr. Jonathan Cabrera/Dr. Lanie B. Laureano
12:00-1:30	Lunch	
1:30-4:00	Continuation	
Day 2 (April 4)		
9:00-10:00	Coastal Zone Vulnerability Assessment Lecture and Activity Workshop	Mr. Jonathan Cabrera
10:00-10:15	Break	
10:15-12:00	Overview of Water Quality Survey	Mr. Amy Ponce Ms. Rheacin A. Polestico
12:00-1:00	Lunch	
1:00-3:00	Presentation of the socioeconomic and cultural assessment survey	Dr. Jeralyn Hemillan-Sacro

		Ms. Cindy Lasco
3:00-4:00	Coastal Zone Vulnerability Assessment Scoring Workshop	Mr. Jonathan Cabrera
Day 3 (April 5)		
9:00-10:00	Coastal Zone Vulnerability Assessment Scoring Workshop	Mr. Jonathan Cabrera
10:00-10:15	Break	
10:15-12:00	Coastal Zone Vulnerability Index Analysis and GIS Integration Workshop	Mr. Jonathan Cabrera
1:00-3:00	Open Forum	
3:30-4:00	Closing Remarks	Dr. Lea A. Jimenez

Pictures:


Republic of the Philippines
DAVAO ORIENTAL STATE UNIVERSITY
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ACTIVITY REPORT OF ON-GOING RESEARCH
F-RAE-013 | Rev. 0 | 01/16/18| Page 8 of 7

CERTIFICATE OF APPRECIATION
IS GIVEN TO
Jonathan Cabrera
For his/her active participation in the **Workshop on Geographic Information System and Its Applications** held on May 9-11, 2023, at Davao Oriental State University.
Given this 11th day of May 2023 at Davao Oriental State University,City of Mati, Davao Oriental, Philippines
Macro- and Micro-Plastic Pollution Research Program funded under CHED-GIA in collaboration with DOrSU-RIC XI and Onsite Team Project of Hiroshima University
MISAEL B. CLAPANO, Ph.D. ROY G. PONCE, Ed.D.

CERTIFICATE OF PARTICIPATION
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MISAEL B. CLAPANO, Ph.D. ROY G. PONCE, Ed.D.

Prepared by:
RHEACIN A. POLESTICO
Project Support Staff V

Noted by:
EMILY S. ANTONIO, Ph.D.
M2P2 Program Leader

Recommending Approval:
MR. JHONNEL VILLEGAS
Director for R&D
MISAEL B. CLAPANO, Ph.D.
VP for RIE

Approved:
ROY G. PONCE, Ed.D.
SUC-President III

2. Workshop on coastal zone vulnerability assessment and its corresponding activities
   Date: May 15, 2024

   Required Time: 14:00-15:00

Outline: This workshop highlights how local government units emphasize monitoring their coastal environment. This section describes case research, monitoring activities, and assessments aimed at preserving the integrity of the coastal zone environment. Furthermore, the topics to be discussed are integral to the onsite team project of the respondents. The first section covers the socioeconomic impacts of changes in the coastal zone environment based on the initial findings of this project. The second section will focus on the physical and chemical assessment of the coastal zone environment, an annual activity conducted by the committee to ensure ongoing monitoring. This presentation will also demonstrate that coastal management policies are informed by research data provided by the committee and other relevant sectors. The goal of this project is to integrate the Onsite Team Project (OTP) into the routine activities of local government units for monitoring the coastal zone environment.

Program:
14:00 – 14:10 – Opening Remarks and Introduction of the Speakers

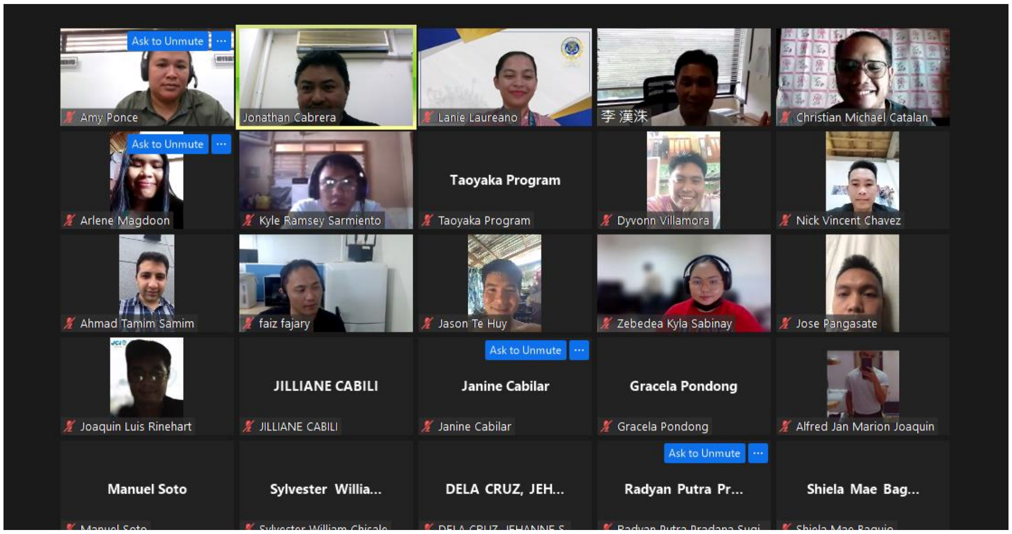
14:10 – 14:25 – Socioeconomic Vulnerability Assessment of the Coastal Zone Environment: A case study of Mati and Davao City
Presenter: Associate Prof. Lanie B. Laureano, DIT
Research Director, Davao Oriental State University
Mr. Jonathan Cabrera
Student, Hiroshima University

14:25 – 14:40 – Assessment of the Physicochemical Characteristics of Pujada Bay for Management Adaptation
Presenter: Ms. Amy G. Ponce
Lecturer, Davao Oriental State University
Committee Member, Shoreline Management – Davao Oriental

14:40 – 14:55 – Questions and answers
14:55 – 15:00 – Closing remarks

Pictures:

TAOYAKA
Workshop on Coastal zone vulnerability assessment and its corresponding activities of Mati and Davao City for coastal management
Date: May 15, 2024
Time: 14:00-15:00 JST
Language: English
14:00 – 14:05 – Opening remarks
14:05 – 14:20 – Topic 1: Coastal Zone Vulnerability Assessment
14:20 – 14:35 – Topic 2: Socioeconomic Vulnerability Assessment on the Coastal Zone Environment
14:35 – 14:50 – Topic 3: Physicochemical Characteristics
Assessment of Pujada Bay for Management Adaptation
14:50 – 14:55 – Questions and answers
14:55 – 15:00 – Closing remarks
Speaker 1
Mr. Jonathan Cabrera
PhD Student, Hiroshima University
Invited Speaker
Ms. Amy G. Ponce
Lecturer, Davao Oriental State University
Committee Member, Shoreline Management – Davao Oriental
Invited Speaker
Lanie B. Laureano, DIT
Associate Professor III
Research Director, Davao Oriental State University
Register Here



CERTIFICATE

OF RECOGNITION

This certificate is proudly presented to:

PROF. LANIE B. LAUREANO, DIT

In recognition of her invaluable services and contributions rendered as **Resource Speaker** during the virtual **Workshop on Coastal zone vulnerability assessment and its corresponding activities of Mati City for coastal management** organized by Taoyaka - Hiroshima University.

Given this 15th day of May 2024

Prof. Dr. Han Soo Lee
Graduate School of Advanced Science and Engineering
Hiroshima University

CERTIFICATE
OF RECOGNITION

This certificate is proudly presented to:

MS. AMY G. PONCE

In recognition of her invaluable services and contributions rendered as **Resource Speaker** during the virtual **Workshop on Coastal zone vulnerability assessment and its corresponding activities of Mati City for coastal management** organized by Taoyaka - Hiroshima University.

Given this 15th day of May 2024

Prof. Dr. Han Soo Lee
Graduate School of Advanced Science and Engineering
Hiroshima University

Expenses:

Date	Accounting No.	Item	Item Details	Quantity	Unit Price	Price	Payee
5/29/2023	RYH010230820-21	Travel to Davao and Mati	Travels to Davao Oriental University and Mati city from March	1	159,381	159,381	CABRERA JONATHAN SALAR

			30th to May 19th 2023				
5/23/2023	SY0000153850	Honorarium	-	1	51,600	51,600	REACIN ARGALLON POLESTICO
5/23/2023	SY0000153842	Honorarium	-	1	51,600	51,600	PONCE AMY
5/23/2023	BP0003897547	Boat rental fee	Mati, April 14	1	8,410	8,410	CABRERA JONATHAN SALAR
					TOTAL	270,991	

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List of Publications

First Author Peer-Reviewed Journals

1. **Cabrera J.** and Lee H.S. 2022. Coastal Zone Environment Integrity Assessment for Sustainable Management: Part 1. Development of Adaptive Expert-Driven Coastal Zone Health Index Framework. J. Mar. Sci. Eng., 10(9):1183. **[Citation: 2]**
2. **Cabrera J.S.** and Lee H.S., 2022. Adaptive coastal zone health index (CoZHI) framework: A tool to assess the co-existence status between sustainable development and coastal zone environment. Journal of Japan Society of Civil Engineers, Ser. B2 (Coastal Engineering), 78(2), I_991-I_996. **[Citation: 1]**
3. **Cabrera J.S.**, Lee H.S. 2024. Recent Decadal Perspective on Sea Level Fluctuations in the Five Ocean Basins Using Improved Complete EEMD with Adaptive Noise Algorithm, *(in preparation).*

Co-author Peer-Reviewed Journals

1. Bhanage V, Lee HS, **Cabrera J**, Kubota T, Pradana RP, Fajary FR and Nimiya H. 2024. Identification of Optimal CMIP6 GCMs for Future Typical Meteorological Year in Major Cities of Indonesia using Multi-Criteria Decision Analysis. Front. Environ. Sci. 12:1341807
2. Aljber M, Lee HS, Jeong J-S, and **Cabrera JS**. 2024. Tsunami Inundation Modelling in a Built-in Coastal Environment with Adaptive Mesh Refinement: Onagawa Benchmark Test. J. Mar. Sci. Eng., 12(1), 177.
3. Hussainzada W, **Cabrera JS**, Samim AT, Lee HS. 2023. Water resource management for improved crop cultivation and productivity with hydraulic engineering solution in arid northern Afghanistan. Appl. Water Sci. 13(2), 41. **[Citation: 1]**
4. Nhiavue Y, Lee HS*, Chisale SW, and **Cabrera J.S**. 2022. Prioritization of Renewable Energy for Sustainable Electricity Generation and an Assessment of Floating Photovoltaic Potential in Lao PDR. Energies, 15(21), 8243. **[Citation: 3]**

Refereed International Conference Proceedings

1. Aljber, M., Sakanoue, G., Jeong, JS., **Cabrera, J.S.**, & Lee, H.S. (2023). Assessment of Potential Tidal Power Sites in the Seto Inland Sea, Japan Using Multi-criteria Evaluation. In: Caetano, N.S., Felgueiras, M.C. (eds) The 9th International Conference on Energy and Environment Research. ICEER 2022. Environmental Science and Engineering. Springer, Cham.
2. Flores C., Lee H.S., Mas E. & **Cabrera J.S**. Tsunami evacuation in a massive crowd event using an agent-based model. Coastal Engineering Proceedings: No. 37 (2022): Proceedings of 37th Conference on Coastal Engineering, Sydney, Australia, 2022.

Peer-Reviewed Conferences and others

1. **Cabrera J.S.**, & Lee H.S., 2024. Analyzing Coastal Environment Using the Coastal Zone Health Index Framework (CoZHI). Hiroshima University-Inha University (HU-IU) Joint Seminar, 28 June, Inha University, Incheon City, South Korea
2. **Cabrera J.S.**, Lee H.S., Jeong J.S., Aljber M., Williams Z., & Calvo M.S. Sea level analysis in major ocean basins using improved complete EEMD with adaptive noise (ICEEMDAN) for data decomposition and k-nearest neighbors (KNN) for data imputation. Japan Society of Civil Engineers (JSCE) CEC conference, 6－8 November 2024, Akita, Japan. *(Accepted)*
3. **Cabrera J.S.**, Lee H.S., Jeong J.-S., & Aljber M. Integrated framework for coastal zone health index and vulnerability assessment. 38th International Conference on Coastal Engineering, 8-14 September 2024, Rome, Italy *(Accepted)*
4. **Cabrera J.S.**, Lee H.S., Jeong J.-S., & Aljber M. Coastal zone environment integrity assessment for sustainable management: Part 2. Coastal zone vulnerability assessment. Japan Society of Civil Engineers (JSCE) CEC conference, 14－17 November 2023, Kyoto, Japan.
5. **Cabrera J.S.** & Lee H.S. A recent decade’s perspective of ocean basin sea level fluctuations using complete ensemble empirical mode decomposition with adaptive noise (CEEMDAN). APAC 2023, 14-17 Nov., Kyoto, Japan.

6. Hussainzada W., **Cabrera J.S.**, Samim A.T., & Lee H.S. Sustainable Water resources management using Soil and Water Assessment Tool (SWAT) and Analytical Hierarchy Process (AHP) for water-scarce northern Afghanistan. AOGS 2023, 30 July – 4 August, Singapore.
7. **Cabrera J.S.** & Lee H.S. Recent Decadal Perspective on Sea Level Fluctuations in the Five Ocean Basins. AOGS 2023, 30 July – 4 August, Singapore.
8. Aljber M., Nogami K., Jeong J.S., **Cabrera J.S.**, & Lee H.S. Tsunami modelling in a built-in environment with adaptive mesh refinement and varying bottom friction. 37th Conference on Coastal Engineering, Sydney, Australia, 2022.
9. Flores C., Lee H.S., Mas E. & **Cabrera J.S**. Tsunami evacuation in a massive crowd event using an agent-based model. 37th Conference on Coastal Engineering, Sydney, Australia, 2022
10. **Cabrera J.S**. & Lee H.S., 2022. Adaptive coastal zone health index (CoZHI) framework: A tool to assess the co-existence status between sustainable development and coastal zone environment. Japan Society of Civil Engineers (JSCE) CEC conference, 11 November 2022, Yokosuka, Japan.
11. **Cabrera J.S.** & Lee H.S. Adaptive Coastal Zone Health Index (CoZHI) Framework for Sustainable Coastal Zone Development and Management: An Expert-Driven Perspectives. Asia Oceania Geosciences Society (AOGS) 19th Annual meeting (2022), 01-05 August 2022, virtual conference
12. Aljber M., Sakanoue G., **Cabrera J.S.,** Jeong J.-S., & Lee H.S. Assessment of potential tidal power sites in the Seto Inland Sea, Japan, using multi-criteria evaluation. ICEER2022 – The 9th International Conference on Energy and Environment Research, 12-16 September 2022.

Unrelated Journal Publications

1. Dumdumaya, C. E., & **Cabrera, J. S.** (2023). Determination of future land use changes using remote sensing imagery and artificial neural network algorithm: A case study of Davao City, Philippines. Artificial Intelligence in Geosciences, 4, 111-118. **[Citation: 3]**

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Awards

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