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Vulnerability of Coastal Communities from Sea Level Rise in Malangas, Dumanquillas Bay, Philippines

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ABSTRACT

The Philippines ranked third among sixty-seven countries as the most vulnerable to climate change. Satellite observations from 1993 to 2015 show that the tropical Western Pacific region, to the east of the Philippines, has experienced a sea level increase of 5-7 mm/yr, about twice the global average. With the archipelagic characteristics of the Philippines and its vulnerability to the effects of climate change, in particular sea level rise (SLR), this study was conducted to determine the vulnerability of the coastal communities to sea level rise in Malangas, Dumanquillas Bay, Zamboanga Sibugay, Philippines based on three aspects, the numerical vulnerability on hazard, sensitivity to sea-level rise, and adaptive capacity. The study utilized projections from National Oceanic and Atmospheric Administration (NOAA) and Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAG-ASA) to estimate future sea-level rise scenarios. Based on the simulation, the findings showed that all barangays had a numerical vulnerability score of 1, indicating that they were exposed to potential sea-level change at the same rate. Barangay Poblacion has the highest level of sensitivity, with a score of 0.261, indicating higher sensitivity to sea level rise. Barangay Sinusayan has the highest adaptive capacity with a score of 0.304, while Barangay Dansulao faced the highest vulnerability to potential sea-level rise with the value 1.053.Variations in sensitivity and adaptive capacity among the barangays highlighted the need for targeted interventions and strategies to enhance resilience and mitigate vulnerability contributing insights for effective coastal management and adaptation measures to prevent loss of life and properties as well as to ensure the sustainability of coastal communities in the face of rising sea levels.

Keywords : vulnerability, coastal communities, adaptive capacity, sensitivity, Dumanquillas Bay

1 INTRODUCTION

Climate change has resulted in increasing land and sea surface temperatures, widespread reduction of snow and ice, and sea-level rises [Intergovernmental Panel on Climate Change (IPCC), 2007], creating adverse impacts on the coastal systems (Snoussi et al., 2008) all over the globe in the recent decades which are risky in the future, especially in the tropical zone (IPCC, 2014). Likewise, the coastal zones are being confronted with various stresses, such as land use change, pollution, and tourism among others. Meanwhile, the global mean sea level had increased continuously from 1.80 to 2 mm/year in 1961–2003 and 1971–2010, respectively, brought about by ocean thermal expansion, and glacier and ice sheet melting (IPCC, 2001; 2013). Sea-level rise which leads to coastal erosion, seawater intrusion, and floods (Sales, 2009; Uy et al., 2011) threatens coastal communities by exacerbating the impacts on their socio-economic and environmental dimensions. These, for instance, impact on the physical environments, fish stocks, ecosystems, coastal infrastructures, as well as on marine and inland fishing operations (Allison, et al., 2008; Shah et al., 2013), and coastal aquaculture, especially in coastal zones of developing countries and small islands (Dow & Downing, 2006).

Global-mean sea-level rise is one of the more certain impacts of human-induced global warming and one that is expected to continue for centuries due to the time scales associated with climate processes and feedback, even if greenhouse gas (GHG) emissions concentrations were to be stabilized (Meehl et al., 2007). Moreover, sea level rise may lead to inundation, tidal variations, alterations in ocean dynamics, saltwater intrusion in estuaries and rivers, reduced productivity of seagrass beds, and decreased yields of mangrove lumber (Capili et al., 2005). The predicted global sea level rise from 1990 to 2100 is approximately 0.09–0.88 meters (IPCC, 2001), which can lead to coastal erosion and increased susceptibility to storm surges, particularly in the Philippines.

The Philippines ranked third among sixty-seven countries as the most vulnerable country to climate change (Paun et al., 2019).

Satellite observations from 1993 to 2015 show that the tropical Western Pacific region, to the east of the Philippines, has experienced a sea level increase of 5-7 mm/yr, which is about twice the global average (Kahana et al., 2016). Moreover, Kahana et al. (2016) presented sea level changes of the Philippine regions from 1993 to 2015 produced from the AVISO satellite observations, showing that the south of Zamboanga in Mindanao Island has a sea level increase of 4.5–5 mm/yr, which is still higher than the global average.

Dumanquillas Bay Protected Landscape and Seascape (DBPLS), commonly known as "Dumanquillas Bay," is a body of water located between the coastal areas of the provinces of Zamboanga del Sur and Zamboanga Sibugay (RA 11038). The bay is the source of marine products like fish, shellfish, sea weeds, and other marine resources in the Zamboanga Peninsula region. Moreover, it is home to 2,303 human households that reside within the protected area (DBPLS Survey on Protected Area Occupants, 2020).

The bay is not exempted from the impact of climate change, particularly sea level rise (Kahana et al., 2016). Assessment of the vulnerability of the bay's coastal barangays to the effects of sea level rise is an important action to manage and adapt to the disastrous impacts of sea level rise on the coast and among the coastal inhabitants.

With the archipelagic characteristics of the Philippines and its vulnerability to the effects of climate change, in particular sea level rise, this study was conducted to determine the vulnerability of the coastal communities to sea level rise in Malangas, Dumanquillas Bay, Zamboanga Sibugay, and its effect on coastal communities by verifying rates of sea level fluctuations and examining its spatial variability. With the effects of climate change becoming more pronounced in the past few years, the nation needs to focus on determining priority areas for sea level rise adaptation.

Specifically, the objective was to determine the Socio-economic Vulnerability Index (SVI) of the coastal barangays of Malangas in terms of:

a. Exposure by mapping and simulating the sea level rise in the eleven (11) coastal barangays of Malangas as projected by NOAA and PAG-ASA for the years 2030, 2040, 2050, 2060, and 2100,
b. Sensitivity by projecting social and physical impacts caused by inundation due to sea level rise in the coastal barangays of Malangas in terms of:
   1) Land loss,
   2) Number of affected households
   3) Population with any sort of disability,
   4) Children <5 years old,
   5) Elderly people > 65 years old, and
   6) Female (%)
c. Adaptive capacity by determining the socio-economic characteristics of the communities in the coastal barangays of Malangas on the impact of sea level rise by identifying:
   1) Social Condition
      a) Number of times household heads participated in community activities in one year,
   2) Human Condition
      b) Percent of people in households having non-dependency rate (age 15–65 years old)
      c) Percent of people in households finished high school,
   3) Institutional Condition
      d) Number of times household heads taught on disaster risk reduction and management (DRRM) in one year,
   4) Economic Condition
      e) Number of people in the household with more than one job
      f) Ownership of land areas by households
      g) Average income of households in one month

2 Methodology

2.1 Study Area

The study was conducted in the eleven coastal barangays of Malangas. Malangas is a fourth-class municipality in the province of Zamboanga Sibugay in Mindanao, Philippines. The coastal barangays of Malangas are part of the Dumanquillas Bay Protected Landscape and Seascape, a national protected area under the Philippines' National Integrated Protected Area System (NIPAS).

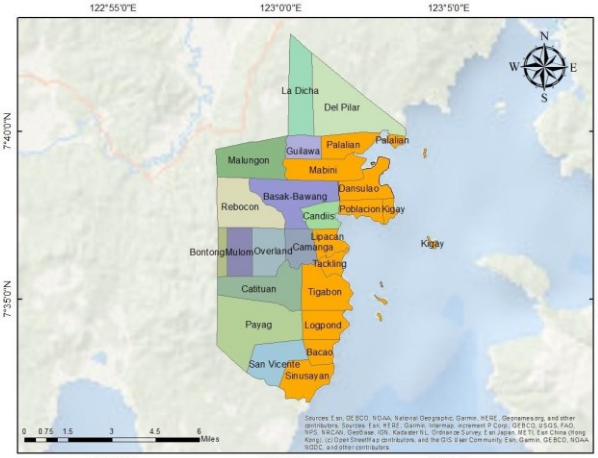


Fig. 1. Map of the Municipality of Malangas

2.2 Data Collection

The study employed a purposive sampling procedure to identify adaptive capacity and sensitivity among residents. Researchers interviewed a total of 627 residents who were living within 100 meters from the seashore to the upland in the coastal barangays of Malangas. One person from each household was selected as the respondent. The primary data collection involved field surveys conducted through interviews using structured questionnaires.

Additionally, exposure was assessed by mapping and simulating sea level rise in the eleven coastal barangays of Malangas. This simulation used projections from NOAA and PAG-ASA for the years 2030, 2040, 2050, 2060, and 2100.

2.3 Data Analysis

The study employed the Kruskal-Wallis test and the Dwass-Steel-Critchlow-Fligner (DSCF) post-hoc method due to the nature of the data not meeting the parametric assumptions required for ANOVA. The Kruskal-Wallis test was utilized to robustly test differences among multiple groups without assuming normality. Following this, the DSCF method was applied to identify which specific groups were significantly different from each other.

Moreover, in determining the projected values of sea level rise in the coastal barangays of Malangas, we used the concept defined by NOAA and PAGASA. All processes are done using ArcGIS software from ESRI.

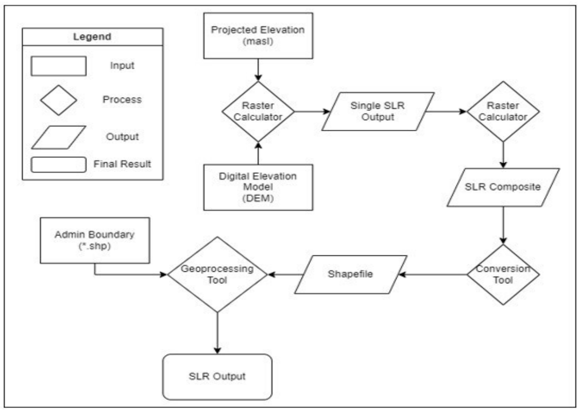


Fig. 2. The flow diagram in generating sea level rise maps.

Both values from low to extreme scenarios were used as input together with the digital elevation model (DEM) to generate tagged image file (TIF) images for each elevation rise. After that, researchers add all TIFs using a raster calculator to generate a composite image of the SLR scenario. Using a conversion tool, researchers generated a shapefile and clipped it with its barangay boundaries to obtain and calculate the area affected by SLR.

3 Results and Discussion

3.1 Sea Level Rise and Level of Numerical Vulnerability on Hazard

The values on sea level rise were based on the projections of NOAA (US) and PAG-ASA (Philippines) (Table 1). Projections used in this study by NOAA were 0.3 meter (low), 1.5 meter (intermediate high), and 2.5 meter (extreme) by 2100. For PAG-ASA projections, the low (0.425 meter) and high (0.595 meter) by 2100 were utilized. PAG-ASA has no intermediate high projection on sea level rise.

Table 1. NOAA and PAG-ASA Projections on Sea Level Change by 2100

Years of Interest	Low (m)		Intermediate High (m)		Extreme/High (m)	
	NOAA	PAG-ASA	NOAA	PAG-ASA	NOAA	PAG-ASA
2030	0.038	0.053	0.188	-	0.313	0.074
2040	0.075	0.106	0.375	-	0.625	0.149
2050	0.113	0.159	0.562	-	0.938	0.223
2060	0.150	0.212	0.750	-	1.249	0.297
2100	0.300	0.425	1.500	-	2.500	0.595

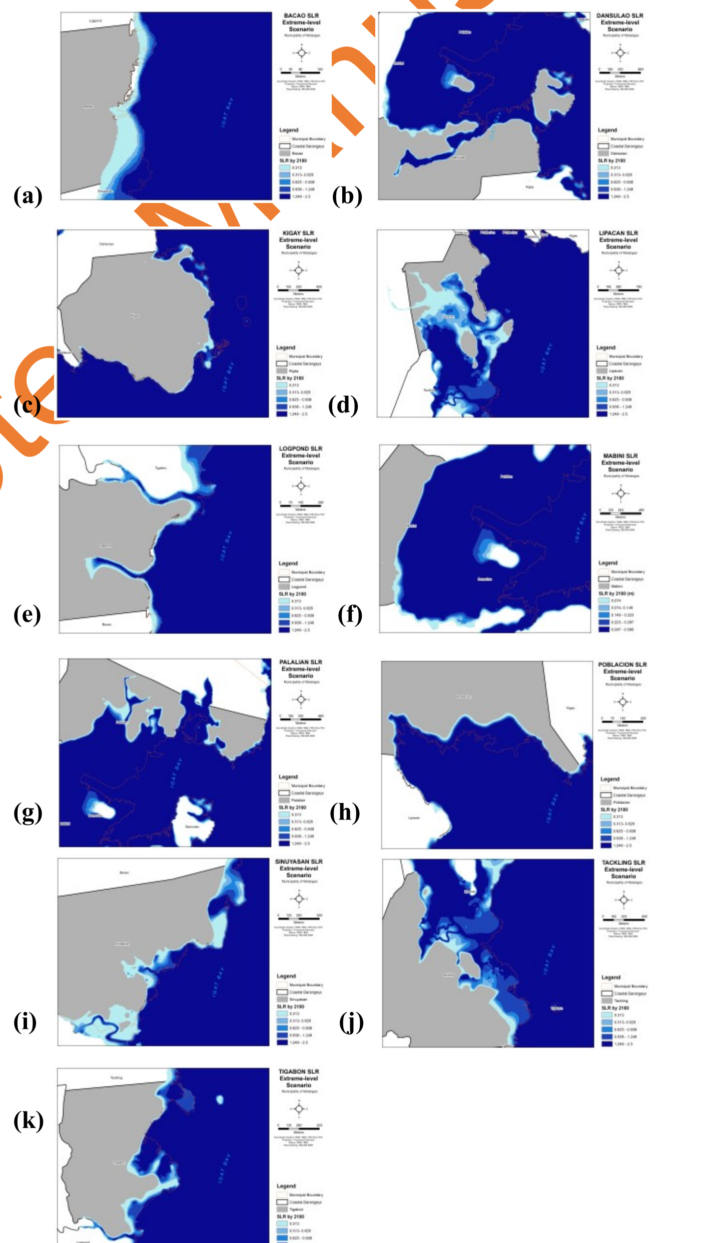


Fig. 3. NOAA SLR projection maps based on extreme level scenario:

(a) Bacao, (b) Dansulao, (c) Kigay, (d) Lipacan, (e) Logpond, (f) Mabini, (g) Palalian, (h) Poblacion, (i) Sinusayan, (j) Tackling, and (k) Tigabon.

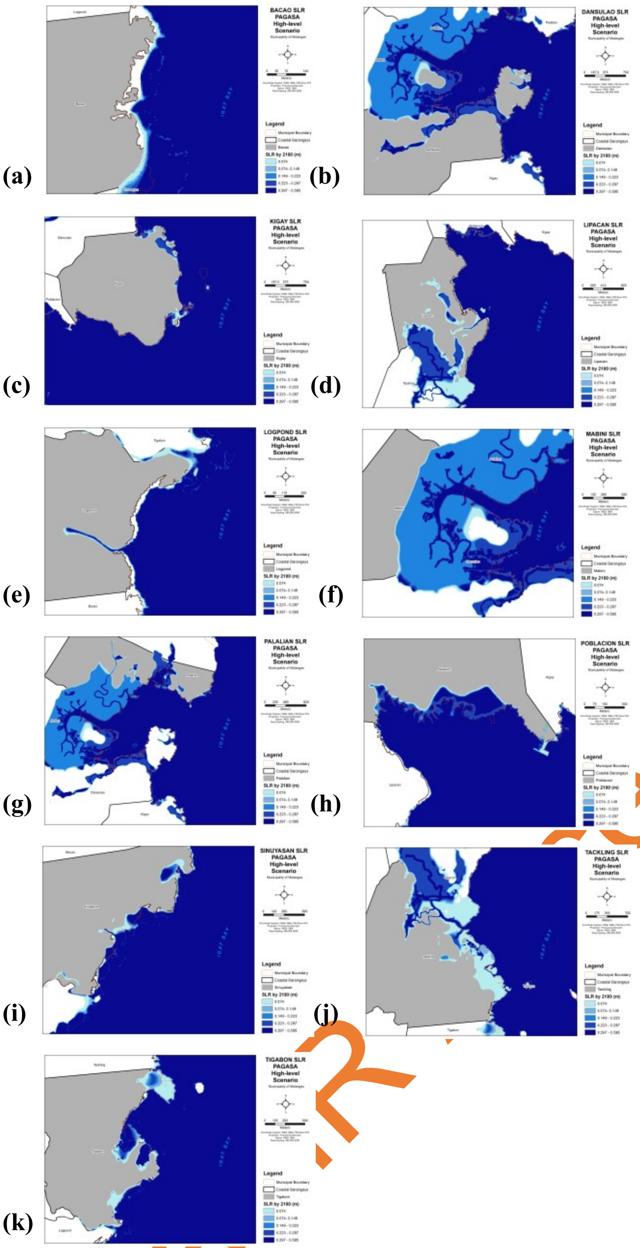
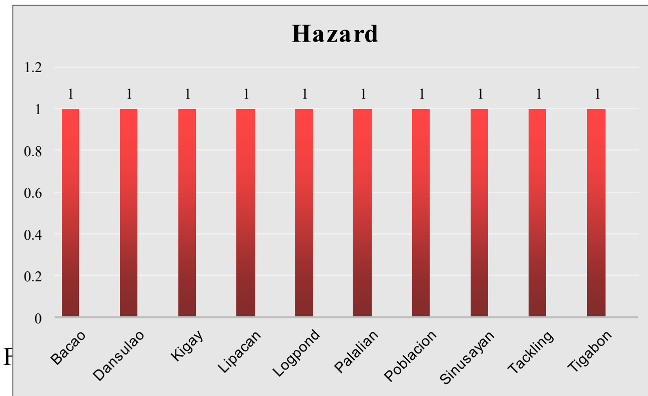


Fig. 4. PAG ASA SLR projection maps based on high level scenario: (a) Bacao, (b) Dansulao, (c) Kigay, (d) Lipacan, (e) Logpond, (f) Mabini, (g) Palalian, (h) Poblacion, (i) Sinusayan, (j) Tackling, and (k) Tigabon.

The simulation illustrated that rising levels of seawater in all barangays resulted in numerical vulnerability on hazard with a score of 1 in each of the barangays. The situation is described in which each barangay is exposed to potential sea-level change at the same rate (Figure 5).



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Further, SLR maps projected by reputable organizations like NOAA and PAGASA provided visual representations of the potential extent of coastal inundation under various scenarios of rising sea levels. On the projections of NOAA and PAG ASA, it can be observed that there's a big gap in the values of SLR between the two. In this study, the researchers have utilized both of the projections to make a global and local view of the increasing sea level change.

For NOAA projections based on the extreme level scenario (Figure 3), by the year 2100, it can be observed that most of the coastal areas have been covered by seawater at a maximum level of 2.5 m. Unlike the PAG ASA projections (Figure 4), it has an increase in sea level of at most 0.595 m. If we compare both projections, NOAA has more likely imposed an alarming view of the global risks of sea level rise. With that, this study has highlighted the need to take urgent action based on this scientifically credible data.

Moreover, assessing exposure and vulnerability to SL) and its physical impacts, such as coastal flooding, has advanced its methodologies since the IPCC 5th Assessment Report. Exposure assessment is frequently based on census data, which is available at coarse resolutions. However, new technologies (e.g., drones and mobile phone data) and more available satellite products provide new tools for exposure analysis. Exposure assessment is increasingly based on the combination of high-resolution satellite imagery and spatio-temporal population modeling, as well as the improved quality of digital elevation models (Kulp & Strauss, 2017).

3.2 Sea Level Rise and Level of Numerical Vulnerability on Sensitivity

Sensitivity is defined by the Intergovernmental Panel on Climate Change (2014, p. 1772) as the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise). The parameters of sensitivity in each barangay were analyzed and then standardized using the Dimension Index formula. Finally, the level of sensitivity of each proxy was compared among the barangays. The paper provided six parameters, such as land loss, number of affected households, population with any sort of disability, children <5 years old, elderly people > 65 years old, and females (%), which showed how significantly and adversely a region or community may be impacted by the physical and social consequences of sea level rise.

3.2.1 Land Loss on Different Sea Level Rise Scenarios

For the NOAA sea level rise projection and land loss (Table 2), the low scenario projection (0.300 meters) by 2100 resulted in a total land loss of 529.3 hectares, with Barangay Palalian experiencing the most significant land loss at 135.6 hectares. For the sea level rise intermediate-high scenario (1.500 meters) by 2100, the total land loss was 914.4 hectares, of which Barangay Lipacan had the most land loss with 192.5 hectares. Lastly, for the extreme sea level rise scenario (2.5 meters) by 2100, the total land loss was 1,042.1 hectares, of which Barangay Lipacan again had the most land loss with 229.1 hectares.

For PAG-ASA sea level rise projection and land loss (Table 3), low scenario projection (0.425 meters) by 2100 resulted in a total land loss of 675.4 hectares, of which Barangay Palalian had the most land loss with 141.6 hectares. Lastly, for the high sea level rise scenario (0.595 meters) by 2100, the total land loss was 675.4 hectares, of which Barangay Palalian again had the most land loss with 147.7 hectares.

Table 2. NOAA Sea Level Rise Projection and Land Loss

Land loss with 0.3-meter sea level rise (low scenario) by 2100

Sea level rise (m)	0 m	0.038 m	0.075 m	0.113 m	0.150 m	0.300 m
Year	2023	2030	2040	2050	2060	2100
Barangay	Area (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)
Bacau	151	3.1	3.4	3.6	3.7	4.1
Dansulao	579	5.2	12.4	64.8	73.6	122.9
Kigay	362	2.0	3.3	12.5	14.9	21.2
Lipacan	356	1.9	6.8	33.3	42.0	54.0
Logpond	211	1.9	2.2	2.6	3.0	3.8
Mabini	497	2.1	4.1	6.2	8.7	62.7
Palalian	436	4.0	8.2	22.0	29.6	135.6
Poblacion	108	1.0	1.6	8.4	42.0	12.3
Sinusayan	378	19.3	21.5	23.1	23.9	30.8
Tackling	482	1.0	14.4	34.6	37.9	52.1
Tigabon	245	10.0	13.1	18.8	20.3	29.9
Total	3,805	51.6	90.9	230.1	268.1	529.3

Land loss with 1.5-meter sea level rise (intermediate-high scenario) by 2100

Sea level rise (m)	0 m	0.188 m	0.375 m	0.562 m	0.750 m	1.500 m
Year	2023	2030	2040	2050	2060	2100
Barangay	Area (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)
Bacau	151	3.8	4.3	4.7	5.0	6.5
Dansulao	579	81.7	126.3	142.7	149.2	166.0
Kigay	362	16.8	23.3	27.3	30.1	37.3
Lipacan	356	44.6	71.7	87.9	116.1	192.5
Logpond	211	3.1	4.0	4.9	5.5	8.0
Mabini	497	12.6	63.3	64.4	65.1	67.7
Palalian	436	42.7	138.4	146.9	151.2	164.8
Poblacion	108	11.2	12.9	13.7	14.3	15.9
Sinusayan	378	24.8	33.7	39.4	44.3	62.9
Tackling	482	40.3	70.4	89.9	103.6	129.7
Tigabon	245	21.5	35.9	44.5	49.4	63.1
Total	3,805	303.2	584.2	666.3	733.9	914.4

Land loss with 2.5-meter sea level rise (extreme scenario) by 2100

Sea level rise (m)	0 m	0.313 m	0.625 m	0.938 m	1.249 m	2.500 m
Year	2023	2030	2040	2050	2060	2100
Barangay	Area (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)
Bacau	151	4.1	4.8	5.4	6.0	9.0
Dansulao	579	123.5	145.1	154.8	162.2	178.3
Kigay	362	21.5	28.4	32.5	35.4	44.1
Lipacan	356	58.4	92.0	139.4	174.4	229.1
Logpond	211	3.8	5.1	6.3	7.5	11.1
Mabini	497	62.8	64.7	65.8	66.9	70.4
Palalian	436	136.2	148.4	155.1	160.7	179.5
Poblacion	108	12.5	13.9	14.8	15.4	17.5
Sinusayan	378	31.3	41.1	49.8	57.4	87.1
Tackling	482	57.5	93.6	112.9	123.9	142.0
Tigabon	245	30.9	46.2	53.9	59.5	74.0
Total	3,805	542.6	683.3	790.7	869.3	1,042.1

Table 3. PAG-ASA Sea Level Rise Projection and Land Loss

Land loss with 0.425-meter sea level rise (low scenario) by 2100

Sea level rise (m)	0 m	0.053 m	0.106 m	0.159 m	0.212 m	0.425 m
Year	2023	2030	2040	2050	2060	2100
Barangay	Area (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)
Bacau		3.2	3.6	3.7	3.9	4.4
Dansulao	579	8.6	62.2	75.1	117.1	128.4
Kigay	362	2.6	11.8	15.4	18.0	24.5
Lipacan	356	5.3	32.8	42.6	46.4	77.5
Logpond	211	2.0	2.5	3.0	3.4	4.2
Mabini	497	3.4	5.8	9.4	61.0	63.6
Palalian	436	5.5	20.5	32.3	130.5	141.6
Poblacion	108	1.2	7.8	10.8	11.4	13.1
Sinusayan	378	20.5	22.9	24.2	25.3	35.0
Tackling	482	4.7	34.0	38.4	41.6	78.0
Tigabon	245	11.5	18.6	20.6	22.6	38.9
Total	3,805	68.5	222.6	275.5	481.2	675.4

Land loss with 0.595-meter sea level rise (high scenario) by 2100

Sea level rise (m)	0 m	0.074 m	0.149 m	0.223 m	0.297 m	0.595 m
Year	2023	2030	2040	2050	2060	2100
Barangay	Area (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)	Land loss (ha)
Bacau	151	3.4	3.7	3.9	4.1	4.7
Dansulao	579	12.2	73.3	118.2	122.7	144.0
Kigay	362	3.3	14.8	18.4	21.1	27.9
Lipacan	356	6.7	41.9	47.1	53.6	90.0
Logpond	211	2.2	3.0	3.5	3.8	5.0
Mabini	497	4.0	8.6	61.4	62.6	64.5
Palalian	436	8.2	29.4	131.4	135.5	147.7
Poblacion	108	1.6	10.5	11.5	12.1	13.8
Sinusayan	378	21.4	23.9	25.6	30.7	40.3
Tackling	482	14.3	37.8	42.2	50.0	91.9
Tigabon	245	13.0	20.3	23.1	29.7	45.4
Total	3,805	90.3	267.3	486.4	526.0	675.4

Intensified climate extremes combined with rising sea levels pose an increasing threat to future coastal security due to the complex and non-linear relationship between relative SLR (RSLR) and erosion (Zhang et al., 2004). Relative SLR has been happening at an accelerated rate, a trend projected to continue during the present century due to global warming (Watson et al., 2015). The potential effects of RSLR can already be observed in areas undergoing strong land subsidence, such as Semarang (Indonesia), where subsidence rates amount to 10 centimeters per year, largely due to extensive groundwater extraction (Marfai & King, 2007). This has caused erosion in the order of 1.5 km close to the city in the last decade, thus also increasing its exposure to coastal hazards.

In the present study, this aligns by acknowledging the potential effects of SLR on coastal areas. The projected land loss of 529 hectares by 2100, as projected by NOOA, further emphasizes the need to address the complex relationship between SLR, erosion, and the resulting vulnerability of coastal communities. The case study of Semarang serves to provide empirical evidence, identify vulnerable areas, highlight local factors, and inform adaptation strategies. By showcasing the tangible impacts of SLR and erosion in this specific context, the case study reinforces the significance of addressing the vulnerability of coastal communities to these environmental challenges.

Thus, coastal defenses, relocation programs, and sustainable development practices will be crucial to manage the economic, social, and environmental impacts of rising sea levels.

3.2.2 Number of Household Inundated on Different Sea Level Rise Scenarios

For NOAA sea level rise projection and number of households inundated (Table 4), low scenario projection (0.300 meters) by 2100 resulted in a total number of households inundated of 240 households, of which Barangay Poblacion had the greatest number of households inundated with 135. For the intermediate-high sea level rise scenario (1.500 meters) by 2100, the total number of households inundated is 728, of which Barangay Poblacion had the greatest number of households inundated with 356. Lastly, for the extreme sea level rise scenario (2.500 meters) by 2100, the total number of households inundated was 1,341, of which Barangay Poblacion again had the greatest number of households inundated with 739.

For the PAG-ASA sea level rise projection and the number of households inundated (Table 5), a low scenario projection (0.425 meters) by 2100 resulted in a total number of households inundated of 315, of which Barangay Poblacion had the greatest number of households inundated with 159. Lastly, for the high sea level rise scenario (0.595 meters) by 2100, the total number of households inundated was 346, of which Barangay Poblacion again had the greatest number of households inundated with 165 houses.

The sea level rise projections from both NOAA and PAG-ASA highlight significant risks, particularly for Barangay Poblacion, which consistently shows the highest number of inundated households across all scenarios. This trend underscores the increasing vulnerability of low-lying areas as sea levels rise, with potential severe social, economic, and environmental impacts.

Additionally, in the article published by National Geographic in 2021, the authors reflect the fact that coastal inhabitants are concentrated in rapidly subsiding areas, including sinking deltas and sinking coastal cities. The problem is especially acute in Southeast Asia, where in 2015, 185 million people lived in coastal floodplains—around 75 percent of the global total. Such people live with the threats of both river flooding and sea level rise, making the coastal barangays in Malangas not exempted from these imposed climatic hazards. If subsidence continues at current rates, far more coastal residents could be at risk in the next few decades. Projected population growth alone will cause the number of people living in coastal floodplains to rise from 249 million in 2015 to 280 million in 2050, the study found. Climate change-driven sea level rise will place another 25 to 30 million people in that flood zone; ongoing city subsidence adds 25 to 40 million more people on top of that.

Table 4. NOAA Sea Level Rise Projection and Number of Household Inundated

Number of Household Inundated with 0.3-meter slr by 2100					
Sea level rise (m)	0.038 m	0.075 m	0.113 m	0.150 m	0.300 m
Year	2030	2040	2050	2060	2100
Barangay	Number of Households Inundated				
Bacau	11	12	13	15	15
Dansulao	0	0	1	1	1
Kigay	0	0	10	13	14
Lipacan	0	0	18	20	0
Logpond	0	6	9	9	9
Mabini	0	0	1	3	4
Palalian	0	0	1	1	1
Poblacion	0	0	30	78	135
Sinusayan	31	38	40	45	47
Tackling	0	0	1	3	3
Tigabon	6	7	9	11	11
Total	48	63	1343	199	240
Number of Household Inundated with 1.5-meter slr by 2100					
Sea level rise (m)	0.188 m	0.375 m	0.562 m	0.750 m	1.500 m
Year	2030	2040	2050	2060	2100
Barangay	Number of Households Inundated				
Bacau	12	13	16	19	23
Dansulao	1	1	5	6	15
Kigay	14	20	25	26	125
Lipacan	20	20	26	26	29
Logpond	9	10	15	15	16
Mabini	3	3	6	7	25
Palalian	1	1	15	16	16
Poblacion	100	135	175	189	356
Sinusayan	45	56	75	80	80
Tackling	3	5	15	16	24
Tigabon	11	15	16	18	19
Total	210	279	389	418	728
Number of Household Inundated with 2.5-meter slr by 2100					
Sea level rise (m)	0.313 m	0.625 m	0.938 m	1.249 m	2.500 m
Year	2030	2040	2050	2060	2100
Barangay	Number of Households Inundated				
Bacau	15	16	20	28	31
Dansulao	1	7	6	11	30
Kigay	14	26	28	115	255
Lipacan	0	26	26	29	35
Logpond	9	17	15	18	19
Mabini	4	6	8	22	27
Palalian	1	16	16	16	28
Poblacion	135	375	389	396	739
Sinusayan	47	75	85	88	121
Tackling	3	17	17	16	35
Tigabon	11	16	18	19	21
Total	240	597	628	758	1341

Table 5. PAG-ASA Sea Level Rise Projection and Number of Household Inundated

Number of Household Inundated with 0.425-meter slr (low scenario) by 2100					
Sea level rise (m)	0.053 m	0.106 m	0.159 m	0.212 m	0.425 m
Year	2030	2040	2050	2060	2100
Barangay	Number of Households Inundated				
Bacau	11	9	15	16	15
Dansulao	0	1	1	1	1
Kigay	0	8	13	14	22
Lipacan	0	17	21	21	23
Logpond	0	4	9	10	12
Mabini	0	1	3	3	3
Palalian	0	1	1	1	1
Poblacion	0	19	80	101	159
Sinusayan	31	29	45	46	57
Tackling	0	1	3	5	7
Tigabon	8	9	11	12	15
Total	50	99	202	230	315
Number of Household Inundated with 0.595-meter slr (high scenario) by 2100					
Sea level rise (m)	0.074 m	0.149 m	0.223 m	0.297 m	0.595 m
Year	2030	2040	2050	2060	2100
Barangay	Number of Households Inundated				
Bacau	12	13	17	18	23
Dansulao	0	1	1	1	1
Kigay	0	7	14	14	22
Lipacan	0	17	22	26	29
Logpond	0	4	11	9	14
Mabini	0	1	3	3	3
Palalian	0	1	1	1	1
Poblacion	0	15	111	119	165
Sinusayan	32	33	51	55	63
Tackling	0	1	6	7	8
Tigabon	9	9	12	13	17
Total	53	102	249	266	346

Table 6. Social Parameters on Sensitivity

Barangay	No. of people with physical disability		No. of children aged lesser than 5		No. of elderly people aged more than 65		No. of females in the house hold		Over all Dimension Index
	Ave	DI	Ave	DI	Ave	DI	Ave	DI	
Poblacion	0.1	0.025	0.6	0.096	0.3	0.108	2.3	0.260	0.261
Kigay	0.0	0.007	0.9	0.154	0.2	0.065	2.9	0.318	0.148
Bacau	0.0	0.000	0.4	0.060	0.1	0.024	1.7	0.190	0.059
Dansulao	0.0	0.000	0.6	0.100	0.2	0.067	2.0	0.222	0.231
Lipacan	0.1	0.016	0.7	0.121	0.2	0.078	2.3	0.258	0.208
Logpond	0.0	0.000	0.4	0.067	0.3	0.107	1.6	0.178	0.065
Sinusayan	0.1	0.018	0.5	0.089	0.2	0.071	2.8	0.306	0.187
Tackling	0.2	0.052	0.5	0.090	0.1	0.042	2.0	0.222	0.169
Palalian	0.0	0.000	0.3	0.048	0.1	0.048	1.7	0.190	0.205
Tigabon	0.1	0.024	0.9	0.151	0.1	0.032	3.2	0.354	0.150
OVERALL	0.1	0.014	0.6	0.097	0.2	0.064	2.2	0.250	0.168

Table 6 shows the index values of the social parameters (population with disabilities, children aged less than 5 years old, elderly people aged more than 65 years old, and female population), which are considered in determining the sensitivity of each coastal barangay in Malangas to potential sea level rise. The quantitative values of the sensitivity were calculated using the Dimension Index equation based on equal weights of all parameters and standardized in scores from 0 to 1. Barangays with high values of sensitivity were more exposed to the negative impacts of SLR than those with low values. Barangay Mabini was not included in the sensitivity paramater calculation because there were no human households residing in its coast.

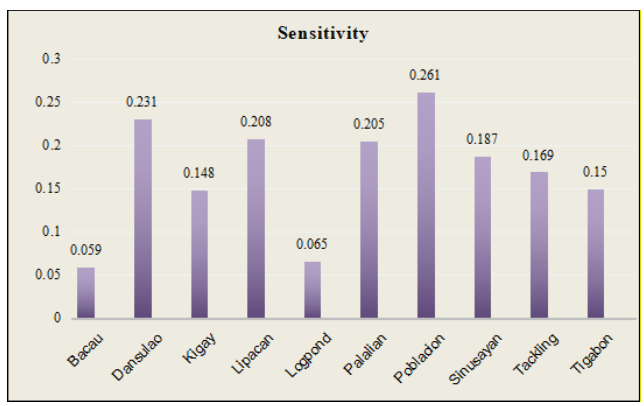

Fig. 6. Sensitivity Dimension Index in each barangay

The findings presented in Table 6 highlight a significant disparity in sensitivity to sea level rise across different barangays in the study area. Barangays such as Poblacion, Lipacan, and Sinusayan, which exhibited the highest Overall Dimension Index values (0.261, 0.208, and 0.187, respectively), are characterized by higher sensitivity. This suggests that these areas are more vulnerable to the impacts of sea level rise. On the other hand, barangays like Bacau, Logpond, and Tackling, with the lowest index values (0.059, 0.065, and 0.169, respectively), demonstrate relatively lower sensitivity, implying a reduced susceptibility to the adverse effects of sea level rise.

These findings can be further contextualized by considering the study "Climate Change, Overcrowding, and Non-Communicable Diseases: the 'Triple Whammy' of Tuberculosis Transmission Risk in Pacific Atoll Countries." This study emphasizes how high population densities and the concentration of essential infrastructure in low-lying, flood-prone areas exacerbate coastal risks. The example of South Tarawa and Male' illustrates that densely populated areas in vulnerable locations are at a heightened risk from climate change impacts.

Applying this to the current study, Barangay Poblacion, identified as the urban center of Malangas, mirrors the situation described in the referenced study. Its high population density and concentration of critical infrastructure make it particularly sensitive to sea level rise. This increased sensitivity is likely due to the combination of exposure to flooding and the potential for significant disruption to both the community and its infrastructure.

In light of these observations, the higher sensitivity index values in Poblacion, Lipacan, and Sinusayan may reflect similar underlying factors, such as higher population densities and more critical infrastructure situated in vulnerable areas. This insight underscores the need for targeted adaptation strategies in these barangays to mitigate the risks associated with sea level rise. Conversely, the lower sensitivity in Bacau, Logpond, and Tackling suggests that these areas may be less affected in the short term, although ongoing monitoring and proactive measures remain essential.

This implies that urban planning and disaster risk reduction strategies should prioritize areas with higher sensitivity indices, focusing on enhancing resilience in densely populated, vulnerable areas. It also calls for further investigation into the specific factors contributing to the sensitivity of these barangays, enabling more precise and effective interventions to safeguard against the growing threat of sea level rise.

Table 7. Test of difference in the adaptive capacity and sensitivity among barangays using One-Way ANOVA (Kruskal-Wallis Test).

Dependent Variables	χ^2	df	p	Interpretation
Adaptive Capacity	20.3	9	0.016	Significant
Sensitivity	349	9	<.001	Highly Significant

Moreover, based on the results of Kruskal-Wallis, a non parametric test on the sensitivity among the barangays, the test yielded to a χ^2(9) value of 349 with corresponding p-value <.001 which also signified to reject the null hypothesis at 0.05 and established significant difference on the sensitivity among the barangays. Hence, it can be concluded from the result that there was a highly significant difference on the sensitivity among the ten barangays (Table 7).

Post-Hoc multiple comparisons using Dwass-Steel-Critchlow-Fligner pairwise comparisons test results showed in terms of sensitivity that barangay Poblacion (MR=426.91, n = 349) was significantly higher than that of barangay Sinusayan (MR = 244.3, n = 28), Tackling (MR = 186.46, n = 24) , Tigabon (MR = 147.48, n = 2), Kigay (MR = 147.20, n = 103), Logpond (MR = 31.76, n = 25) , and Bacau (MR= 24.86, n = 14), but was significantly the same with that of barangay Dansulao (MR=365.87, n = 15), Lipacan (MR=287.49, n = 47), and Palalian (MR = 278.71, n = 7). Moreover, the results also revealed that barangay Logpond (MR=31.76, n = 25) and Bacau (MR=24.86, n = 14) were significantly lower in sensitivity than the rest of the barangays. The results also indicated that barangay Dansulao, Lipacan and Palalian were significantly higher in sensitivity than barangay Tackling and Tigabon but were significantly the same with barangay Sinusayan. Lastly, barangay Sinusayan was significantly higher in sensitivity than barangay Kigay but was significantly the same with barangay Tackling and Tigabon.

In simpler terms, the study identified certain barangays that were less responsive to the factors being measured (Logpond and Bacau) and others that were more responsive (Dansulao, Lipacan, Palalian, and Sinusayan). There were also some similarities in sensitivity levels between certain barangays (Dansulao, Lipacan, Palalian, and Sinusayan) and differences compared to others (Tackling, Tigabon, and Kigay). Therefore, it can be concluded that Barangay Poblacion had the highest sensitivity, making the area the most exposed to climatic hazards.

3.3 Change and Numerical Vulnerability on Adaptive Capacity

Adaptive capacity is defined by Cutter, Boruff, and Shirley (2003) as the system's faculty to improve its present and future resilience in the face of the occurrence of stresses and changes. Resilience and adaptive capacity are correlated concepts once resilience can be understood as a characteristic of a system to absorb shocks by avoiding reaching an irreversible state through regeneration after the stress (Miller et al., 2010). The parameters of adaptive capacity in each barangay were analyzed and then standardized using the Dimension Index formula. Finally, the adaptive capacity of each proxy was compared among the barangays. Six parameters, including frequency of attendance in community disaster-related activities, non-vulnerable age rate, level of education, income, diversity of jobs, and land ownership, were considered at the household level, while climate change-relevant plans or activities were included as representative of the collective condition. Information on these selected parameters was collected at the local level to ensure that the individual and collective demonstrated capacity of barangays in terms of livelihood, including institutional conditions to cope with the future impacts of sea-level rise, was considered. The parameters associated with the parameters of livelihood assets presented in the study of Uy et al. (2011) were necessary to suitably explain the effective responses of social resilience in the target communities.

In the study area, barangays have unequal values of the indicators of adaptive capacity, indicating that barangays with lower values of each indicator are more susceptible to sea-level rise when it happens than barangays with higher values of each indicator.

In the study entitled "Assessing Vulnerability to Climate Change Impacts in Cambodia, the Philippines, and Vietnam: An

Analysis at the Commune and Household Level" by Mendoza et al.

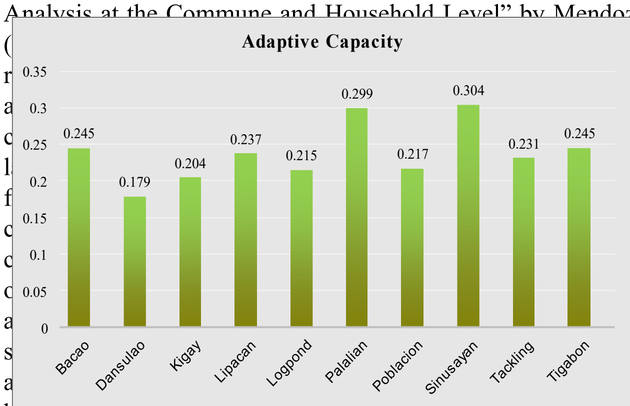

Fig. 7. Adaptive capacity dimension index in each barangay

households are found to be vulnerable. Low adaptive capacity was found to be a key determinant of household vulnerability to climate change across countries. Women were found to be more vulnerable to climatic hazards than men due to limitations in skills and opportunities, but they were given more obligations to take care of family members during risk hazard response and rehabilitation periods.

Table 8. Adaptive Capacity Dimension Index in each barangay

No.	Barangay	Dimension Index				
		Social Condition	Human Condition	Institutional Condition	Economic Condition	Overall Adaptive Capacity
1	Poblacion	0.120	0.254	0.321	0.174	0.217
2	Kigay	0.165	0.209	0.367	0.078	0.204
3	Bacao	0.301	0.193	0.351	0.135	0.245
4	Dansulao	0.125	0.168	0.319	0.104	0.179
5	Lipacan	0.309	0.167	0.395	0.075	0.237
6	Logpond	0.265	0.113	0.407	0.075	0.215
7	Sinusayan	0.374	0.274	0.454	0.117	0.304
8	Tackling	0.168	0.288	0.288	0.179	0.231
9	Palalian	0.393	0.203	0.470	0.129	0.299
10	Tigabon	0.264	0.226	0.409	0.083	0.245
	OVERALL	**0.248**	**0.209**	**0.378**	**0.115**	**0.238**

Table 8 showed the index values of the socioeconomic parameters (social condition, human condition, institutional condition, and economic condition) which are considered in determining the adaptive capacity of each coastal barangay in Malangas to potential sea level rise. The quantitative values of the adaptive capacity were calculated using the Dimension Index equation based on equal weights of all parameters and standardized in scores from 0 to 1. Barangay with high scores were considered as having more adaptive capacity than barangay with low scores.

The results from the calculation (Table 8), indicated that Sinusayan had the highest capability to adapt to potential sea-level rise with a score of 0.304, followed by Palalian (0.299), Bacao and Tigabon (0.245), Lipacan (0.237), Tackling (0.231), Poblacion (0.217), Logpond (0.215), and Kigay (0.204). Meanwhile, with a score of 0.179, Dansulao had the lowest adaptive capacity due to low income and less participation in disaster related capacity building activities at the barangay. The barangay with a high adaptive capacity indicates higher capacity for alleviating the effects of rising sea level-relevant consequences than the barangay with low adaptive capacity (Figure 7). Moreover, based on the results of Kruskal-Wallis, a non-parametric test on the adaptive capacity among the barangays, the test yielded to a (9) value of 20.3 with corresponding p value of 0.016 which implied to reject the null hypothesis at 0.05 and established significant difference on the adaptive capacity among the barangays. Hence, it can be concluded from the result that there was a highly significant difference on the adaptive capacity among the ten barangays (Table 7).

Post-Hoc multiple comparisons using Dwass-Steel-Critchlow-Fligner pairwise comparisons test results revealed that barangay Sinusayan (MR = 409.79, n = 28) had a significantly higher adaptive capacity than that of barangay Dansulao (MR = 227.02, n = 15), but was significantly the same with the rest of the barangays. Furthermore, the results also showed that barangay Dansulao was significantly the same in adaptive capacity in all the barangays except with that of barangay Sinusayan. Therefore, the result concluded that Barangay Sinusayan was significantly higher in adaptive capacity among all the nine (9) barangays. The rest of the barangays were significantly equal in adaptive capacity.

3.3 Socioeconomic Vulnerability Index

Overall, the socioeconomic vulnerability index of coastal communities in the study area based on three aspects (Table 9) indicated that Barangay Dansulao faced vulnerability to potential sea-level rise at the highest level with a score of 1.053. Poblacion ranked the second most vulnerable barangay with a score of 1.044, followed by Lipacan (0.237), Kigay (0.944), Tackling (0.938), Palalian (0.906), Tigabon (0.905), Sinusayan (0.883), and Logpond (0.85) (Figure 8).

Table 9 . Socio-economic Vulnerability Values in each barangay

Barangay	Socio-economic Vulnerability Index	Hazard	Exposure	Adaptive Capacity
Bacao	0.814	1	0.059	0.245
Dansulao	1.052	1	0.231	0.179
Kigay	0.944	1	0.148	0.204
Lipacan	0.971	1	0.208	0.237
Logpond	0.85	1	0.065	0.215
Palalian	0.906	1	0.205	0.299
Poblacion	1.044	1	0.261	0.217
Sinusayan	0.883	1	0.187	0.304
Tackling	0.938	1	0.169	0.231
Tigabon	0.905	1	0.150	0.245

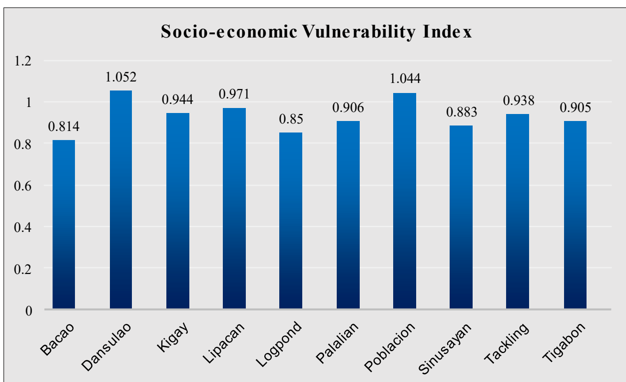

Fig. 8. Socioeconomic Dimension Index in each barangay

The Socioeconomic Vulnerability Index has been identified as an effective tool for analyzing vulnerability at the household level. It enhances disaster management intervention by increasing knowledge about disaster implications at the household level and assisting in location-specific vulnerability assessment (Ahsan & Warner, 2014; Kontogianni et al., 2019; Sorg et al., 2018). The definition of vulnerability to climate change in the national plan refers to the concepts of exposure, resilience, sensitivity, and adaptive capacity. It follows the starting point approach to vulnerability proposed by Kelly & Adger (2000), as the degree of vulnerability is not determined according to future scenarios and future impacts of climate change but instead is measured according to the present ability or inability of a system to deal with certain climate stresses.

In our study, Barangay Dansulao was identified as the most vulnerable among the coastal barangays in Malangas. This heightened vulnerability is primarily attributed to its low adaptive capacity, which is reflected in four critical dimensions: social condition, human condition, institutional condition, and economic condition. These factors collectively suggest that the residents of Dansulao are at a significant disadvantage in terms of their ability to respond to and cope with the challenges posed by sea-level rise and its associated impacts.

4 Conclusion

The research assessed the vulnerability of Malangas' coasts to rising sea levels and its impact on coastal communities by verifying rates of sea level fluctuations and examining their spatial variability. The vulnerability assessment was conducted based on three aspects: numerical vulnerability to hazards, sensitivity to sea-level rise, and adaptive capacity.

On the numerical vulnerability to hazards, the simulation showed that all barangays had a numerical vulnerability score of 1, indicating that they were exposed to potential sea-level change at the same rate. This suggested that regardless of the specific characteristics of each barangay, they all face a similar level of hazard in terms of rising seawater.

On the sensitivity to sea-level rise, the results indicated that Sinusayan had the highest Overall Dimension Index values, indicating higher sensitivity to sea-level rise. On the other hand, Bacau, Logpond, and Tackling had the lowest Overall Dimension Index values, suggesting relatively lower sensitivity. Therefore, the barangays with higher sensitivity are expected to be more adversely impacted by the physical and social consequences of sea-level rise compared to those with lower sensitivity.

On the adaptive capacity, the results showed that Sinusayan had the highest adaptive capacity score, followed by Palalian, Bacao, Tigabon, Lipacan, Tackling, Poblacion, Logpond, and Kigay. Dansulao had the lowest adaptive capacity due to the lack of households living on its coast. Higher adaptive capacity suggests a higher capability to manage and cope with the impacts of rising sea levels through inundation.

Overall, the vulnerability of coastal communities in the study area based on three aspects indicated that Barangay Dansulao faced the highest vulnerability to potential sea-level rise with a value of 1.053 that indicates several key issues. Socially, the community may lack strong networks or access to essential services, limiting their ability to organize and respond effectively in times of crisis. Human condition factors, such as education and health, might be underdeveloped, reducing the residents' awareness and preparedness for climate-related risks. Institutionally, the absence of robust governance structures or disaster response mechanisms could leave the barangay without the necessary support to manage the impacts of sea-level rise. Economically, limited income and resources further constrain the ability of households to invest in protective measures or recover from adverse events.

5 Recommendations

Based on the findings of the study, the following recommendations can be made to address the vulnerability to potential sea-level rise in the studied barangays:

1. Enhance community resilience through community-based disaster preparedness and response activities.
2. Develop targeted interventions based on the varying sensitivity levels of barangays.
3. Improve adaptive capacity through education, income generation,

and collaboration.
4. Implement integrated coastal management, including sustainable land-use planning and nature-based solutions.
5. Foster multi-stakeholder collaboration to address sea-level rise challenges.
6. Integrate sea-level rise considerations into long-term planning and policy frameworks.
7. Empower local communities by involving them in decision-making and building their capacity to adapt.
8. To endorse the results of this study as a basis for the formulation of Malangas' Sea Level Rise Adaptation Plan.

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