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Coastal Dynamic Characteristics and Hazards along the Coastal Region of Myanmar

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Abstract

Myanmar's coastal region, characterized by its dynamic interactions and vulnerabilities, is an area of immense environmental and socio-economic significance. This review examines the mechanisms shaping the coastal dynamics and the hazards that threaten the coastal region of Myanmar. The analysis begins by addressing the influence of Myanmar's coastal currents, which play a pivotal role in the region's hydrography and ecological balance. The wind-wave climate, a key driver of coastal processes, is scrutinized for its impact on erosion and sediment transport. A major focus of this study is the relationship between storm surges and tropical cyclones; frequent phenomena that contribute to widespread destruction along the Myanmar coast. Additionally, the review highlights the tsunami threats that have impacted the region, emphasizing their unpredictable nature and catastrophic potential. Coastal erosion, driven by natural forces and human activities, emerges as a persistent challenge, gradually reshaping Myanmar's shoreline. The discussion extends to sea level rise, an ever-growing concern linked to climate change, and its far-reaching consequences on coastal stability. Moreover, anthropogenic impacts such as land reclamation, deforestation, and urbanization are underscored, revealing their significant role in altering the coastal landscape and exacerbating vulnerability. By synthesizing these elements, the review provides a holistic understanding of Myanmar's coastal dynamics and hazards, offering critical insights into sustainable management and adaptive strategies to protect this fragile environment.

Keywords: Coastal Region of Myanmar; Review; Wind-Wave Climate; Storm Surge and Tropical Cyclone; Coastal Erosion; Sea Level Rise and Anthropogenic impact.

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1. Introduction to Myanmar Coast and Current Threats

Coastal regions of the world host 40% of the world population and have significant ecological and economic value [4&15]. It is estimated that around 649,000 km^2 is less than 2 m above sea level making them very vulnerable for climate change and 62% is in the tropics [1]. Moreover, the socio-economic pressure of coastal regions, both on land and sea, has damaged and is further jeopardizing coastal regions. In a recent study, 13.6% or 36,097 km of the world's coasts are eroding/are damaged. These pressures are increasing due to the predicted global sea level increases. Therefore, coastal protection is urgently needed.

Also, the Myanmar coastal region is affected by flooding, erosion, and inundation. The coastline of Burma (Myanmar) is about 2,300 km long, has diverse geomorphological characteristics and consists of four distinct parts; the western Arakan (Rakhine) coast, the southern Irrawaddy (Ayeyarwady) deltaic coast and Gulf of Mattaban, and the north-south Tanintharyi strip plus more than 1700 islands. The physiography of respective coastlines of Myanmar is described in figure 1 and Table 1.

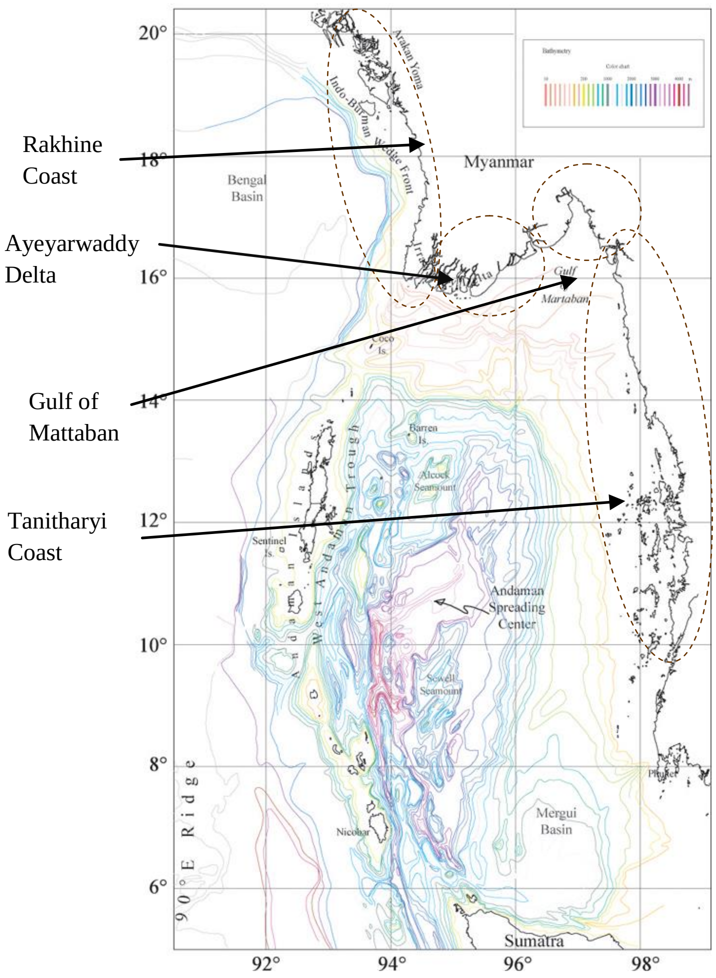


Figure 1: Coastal Region of Myanmar

Natural hazards are abundant along Myanmar coasts such as tropical cyclones, storm surges with coastal flooding, tsunami, sea level rise, erosion; and landslides in southern Tanintharyi coast. For monitoring and understanding the changes and vulnerability of coastal region of Myanmar, a rigorous scientific approach is

Table 1: Physiography of Coastal Region of Myanmar

Attribute	Rakhine	Ayeyarwady Delta	Gulf of Mattaban	Tanintharyi
Geomorphology	-740 km long - Shallow and deltaic in upper region (muddy) - Off shore Islands with extensive estuaries and creeks in middle part - Rugged and rocky stretch with extensive tidal mud flats in southern part(Sandy beaches composed of fine sand) -brackish water - Mangrove, coral reef and sea grass as habitats - Nanthar Island and Mayyu Estuary awared as Ramser site in 2020	-460 km long -Very shallow continental shelf - Flow into the Adman Sea with nine tributaries -Mud dominated sediment and annual sediment discharge of the Ayeyarwady River estimated as 250 million ton in general -80 percent of the delta is under 5 meter above mean sea level - extensive mangrove forest (brackish and washover type) -Meinmahla Kyun was listed as Ramser wetland in 2017	-232 km long - forming bell shaped stating from the east coast of Yangon river to the end at the mouth of Thanlwin River - Relatively shallow shelf; very dynamic; extensive and unique intertidal mudflat environment - Mangrove forest in southern part - Designated as Ramser site in 2017	-1200 km long -Bounded by Adman Sea in the west -alluvial lobe in the north; numerous sand spits and beaches in the middle and,southern part is fringed by numerous islands with many bays and headlands -Coral reef surrounds the outer islands and mangroves cover much of the inner islands - MyeikArchiopolg as Ramser site
Coastline Dynamic	-Erosion in northern Rakhine coast -Land expansion in Middle part -Invariant in Southern Rakhine coast	-Accretion in eastern part and erosion in wester sector of lower delta in general	-Erosion in upper region due to powerful tidal bore -Accretion in southern part because of deposited sediment of delta	-Invariant coastline
Physical Process	-Wave dominate in general -Brackish water and slumpy -Almost 80% of cyclone from BOB made landfall over 45 years period	-Tide dominated type but wave action also predominated -Strong seasonal wave in western part -Fresh and salt water mixing zone -20 % percent of BOB cyclone made landfall	-Tide dominate region -Free from direct hit of cyclone impact	-Tide dominate region -No historical record of cyclone landfall due to shelter effect of Adman Islands
Coast line classification [Tectonic based classification]	-Leading-edge or collision coasts	-Both wave ad tide dominated delta plain -Marginal sea coast	-Marginal sea coast	-Marginal sea coast

warranted and should involve both problem-driven research and action research. As there is no protective hard infrastructure alongside the coastline in Myanmar, it is essential to design and manage natural and sustainable coastal protection measures. To design such for the driver sand sensitive Myanmar coastal regions, the understanding of dynamic nature of the coastal region needs to be improved. Such fundamental process understanding is paramount to further process-based modelling. This study intends to contribute to the knowledge of the Myanmar coastal system in relation to coastal degradation due to natural hazards as a vital first step for resilient and climate adaptation strategies.

In the following, we will first describe the various coastal dynamic drivers: wind waves in section 2, storm surges in section 3 and tsunamis in section 4. We give an overview of coastal degradation in Myanmar in section 5. In section 6, we summarize the present knowledge on sea level rise along the Myanmar coast and in section 7 the anthropogenic changes in the coastal regions are given. We finalize the review with the identification of knowledge gap and recommendation.

1.1. Wind-Wave Climate

The shape of the coastline and the depth of near shore waters both exert a strong influence over the patterns of waves reaching the shore. Wind generated waves play an important role in controlling the physical processes in a coastal environment and need to understand its variability for effective sustainable coastal zone adaptation measures. Bay of Bengal and Adman Sea are influenced by seasonal monsoon climate, both summer and winter monsoon. The 'summer' monsoon from mid-May to October, known as the southwest (SW)monsoon, is characterized by heavy precipitation and thus high river discharge. Winds are predominantly from the southwest and the area generally experiences more energetic conditions, i.e. large waves and strong winds. In contrast, the 'winter' northeast (NE) monsoon is the dry season from November through February and is characterized by low precipitation, low fluvial discharge, and smaller wave energy. Winds weaken and switch direction to originate from the northeast [12&22].

Due to the lack of long term in-situ wave data from buoys or pressure sensors, physical modelling is required to predict the characteristics of the wave along the coastal region of Myanmar. One of the earliest studies on offshore wave was conducted by author [16] at northern part of the Rakhine coast near Sittwe Port at an offshore location with 15 m water depth. Time series of significant wave height (Hs) and average wave period (T_z) was modelled using the numerical wave prediction model DOLPHIN (Figure 2). Estimated average significant wave height and average wave period during the period of 1998 to 2001 reported as 0.6 m and 3 s. The author [36] analysed the wave characteristics along the southern part of Myanmar coast line simulated by SWAN (Simulating WAves Nearshore) model (http://swan.tudelft.nl) and compared the results with satellite data and field measurement data (wave buoy measurement March 2012-March 2013).

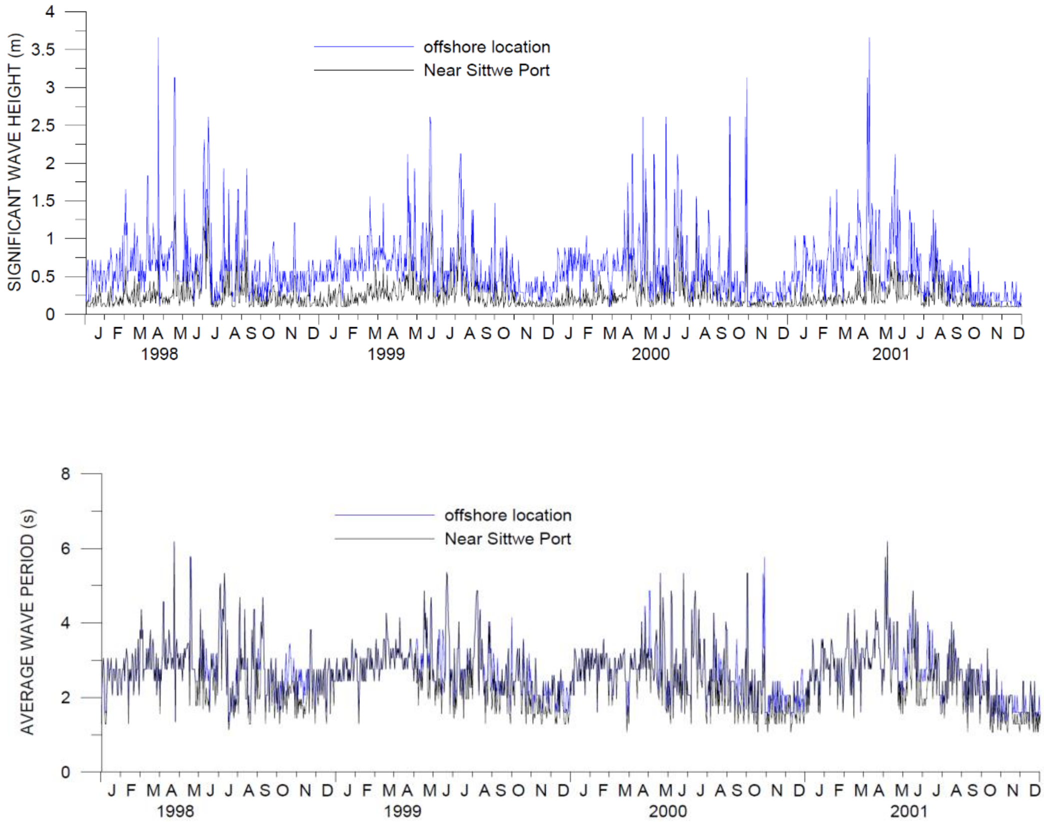


Figure 2: Estimated significant wave height and average wave period at off-shore location and near Sittwe Port [16]

From the analysed result, the average significant wave height was 0.5m and average wave period was 6.8 s. Based on the wave buoy measurement, Hs was higher in May to September and lower Hs in October to April. Yearly maximum Hs was around 2 m which occurs in June and September, mostly originates from the WSW (west-southwest) direction prevailing wind. Wave frequency spectrum and directional spectrum analysis was done using Fourier transformations by the author [35]. His result showed that the wave spectrum can be characterized as a single peak spectrum with highest wave energy found during the summer from SW direction, a concentration of energy between an angle of 200-250 degrees (Figure 3).

In 2016, the time series of wave data ,from 1979 to 2015, in total 35 years of hindcast wave data from WAVEWATCH III, a global wind-wave model developed by the NOAA; WAVEWATCH III Model Description ; was observed and analysed using the peak-over-threshold method and validated its accuracy with data derived from satellite altimetry and wave droid (wave buoy) set up at west coast near Chaung Thar and Ngayoke Kaung at around 10-15 m water depth. The author [10] showed that monsoon significant wave is about twice as high as dry season and mostly driven by south-western wind. The highest wave heights were found in northern part of the Myanmar cost and lower wave heights were found in southern part due to sheltering effect of Adman islands. Average significant wave high per season from 1979 from 2015 which was retrieved form WAVEWATCH III Hindcasts is shown in Figure 4.

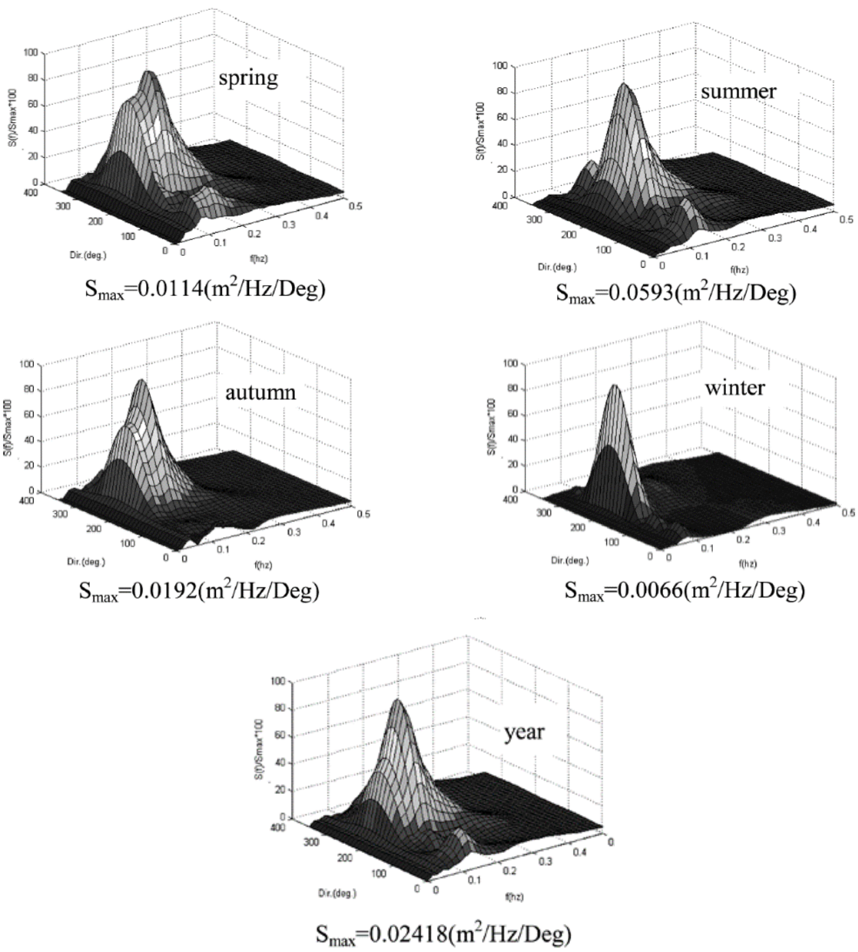


Figure 3: Directional wave spectrum per season (top) and year (bottom*)*[35]

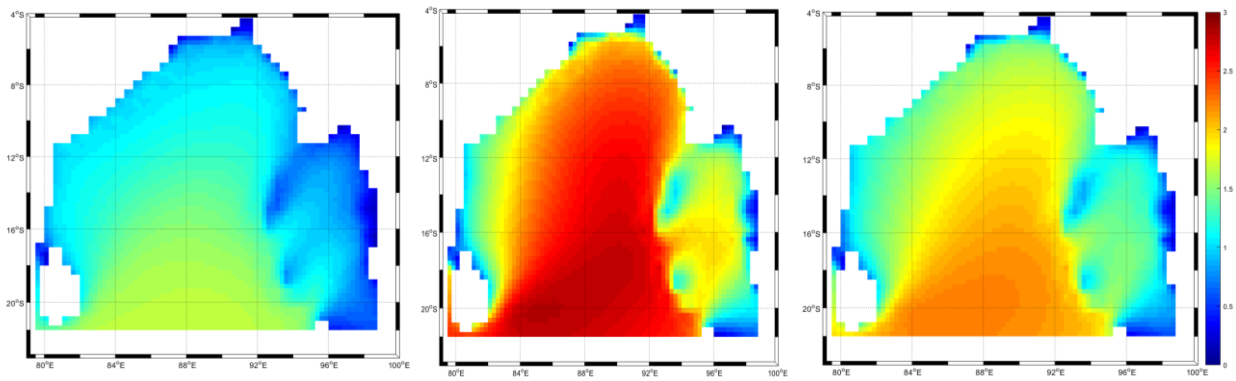


Figure 4: Average Significant Wave Height per season from 1979 to 2015 [10]

There is a contradiction in these above findings with the author Xiao [35] that wave spectrum is characterized as a double peak spectrum, both wind and swell wave according to measurement of wave buoy. To close the knowledge gap of wave behaviour and wave characteristics along the coast of Myanmar, [author 28], 2018 simulated and predicted wave characteristics along the coastal regions of Myanmar by using a third-generation of the waves model SWAN and validated the results withSverdrup-Munk-Bretschneider (SMB)empirical formulae as first analysis and compared the data set from ECMWF for three specific points (shown in figure 5).

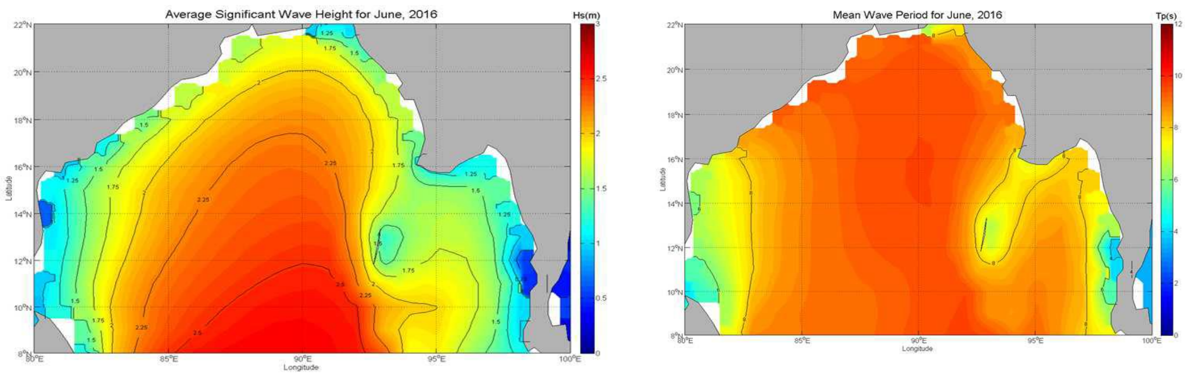


Figure 5: Average Significant Wave Height and Mean Wave Period in June,2016 [28]

The simulated result (Figure 5) of average significant wave high and wave period for June as maximum wind speed occurred in June based on monthly long term mean wind speeds for SW monsoon. Based on the wave contour map, the average significant wave height and wave periods are about 1.5 to 1.75m and 6 to 8 sec in west coast and 1.25 to 1.5 m and 8 to 10 sec at southern coast respectively.

1.2. Storm Sure Associated with Tropical Cyclone

Myanmar coastal zone is bounded by Northern Bay of Bengal (BOB) in the west and Adman Sea (AS) in the south which is the part of North Indian Ocean. On average five to six tropical cyclones form in the basin every year, mostly formed in BOB during the month of May to June (pre monsoon) and October to December (post-monsoon) with peaks at May and November (NIO tropical cyclone, 2022). The tropical storms that form during the monsoon period June to September are weak and have a short life pan. Monthly tropical storm that formed during the period of 1990-2020 in North Indian Ocean is presented in Figure 6.

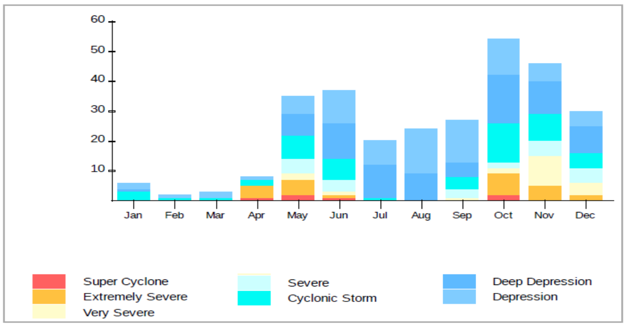


Figure 6: Historical storm formation by month (1990-2020)

Based on historical cyclone data (45 years from 1973 to 2017), 19 cyclones were reported to have made landfall along Myanmar coast, 15 cyclones in Rakhine coast and 4 cyclones in Ayeyarwady delta. The Tanintharyi coast was generally free from cyclone induced disaster. Tropical cyclone induced hazards such as storm surge and associated risk vary significantly depending on geographical area (eg. topography and bathymetry, presence of rivers, vegetation or reef and flood protection measures).

The Myanmar coast generally has gentle slopes and high tide signal, consequently the Myanmar coast line tend to experience the highest vulnerable to storm surge. Tides in the BoB and AS are semi-diurnal in nature and the largest tidal constituent is M2 (12.42 h), known as the principal lunar semidiurnal constituent. Semidiurnal S2 is the second largest tidal constituent and the ratio of maximum tidal elevation of other major tidal constituents such as S2 , N2 , K1 , and O1 with respect to M2 in this region is 44%, 16%, 11% and 6% respectively (Shindu,2013).The distribution of the tidal ranges (spring and neap tide range) in April are 2.3 m and 1 m at Sittwe station which is located at north Rakhine coast, 2.4 m and 0.9 m at Diamond island or Thamee Hla Kyun station, near Pathein river mouth of Ayeyarwaddy delta and 5 m and 2.3 m Amherst station, tidal station near Chaung Sone Kyun at Gulf Martaban. Tidal range within the Gulf of Martaban can reach upwards of seven meters, with tidal currents approaching 3 m/s during spring tide [24] & [23].

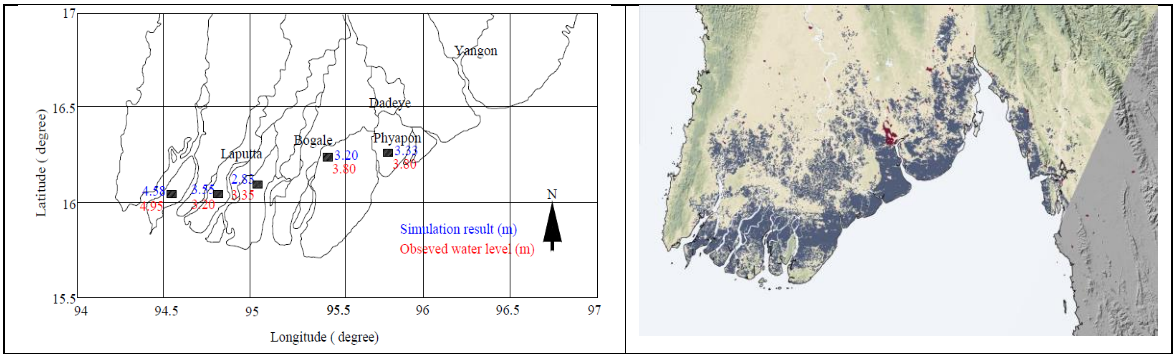
After the tragic event of cyclone Nargis (2008), a number of studies have been undertaken on the various numerical storm surge simulations combine with tide along Myanmar coast. Observed peak surges associated with large catastrophic cyclones that made landfall along Myanmar coast is presented in Table 2. Analysis of flood inundation extent is very important for future mitigation by structural and non-structural measures and flood inundation model is limited by the available data.

Table 2: Historical Surge High Associated with Tropical Cyclones that crossed Myanmar Coast

No	Date	Name	Landfall Point	Peak Surge(m)	Death Toll	Damage (Million USD)
1	7.5.1968	Sittwe	Sittwe	4.25	1037	2.5
2	7.5.1975	Pathein	Pathein	3.0	304	No data
3	4.5.1982	Gwa	Gwa	3.7	31	No data
4	2.5.1994	Maungdaw	Maungdaw	3.66	10	10
5	29.4.2006	Mala	Gwa	4.57	37	No data
6	2-3.5.2008	Nargis	Heingyi	7.01	138,000	4000
7	22.10.2010	Giri	Kyaukphyu	3.7	2157	57

The field survey of three month after Nargis provided that inundation distances reached 50 km inland from the nearest coastline based on flood direction [7]. The author [19] analyzed the flood inundation extent by using simplified 2D overland flow model and validated with observed data Fig(7-a). As the limitation of the author

Nay is that 15sec (~500m) resolution DEM is used and mainly considered for the floodplain flows in the study. If a high-resolution DEM such as 30m resolution may become more suitable and accurate the model result for the prediction of inundation extent. The Nagis flooding extent was developed by the author [20] from the University of Maryland’s Department of Geography, using the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors on NASA’s-Terra-and-Aqua satellite. According to the natural condition, Ayeyarwady delta is highly vulnerable to storm surge due to its low attitude, several open bell shapes tributaries and very shallow slope. In contrast, the Rakhine coast is the highest vulnerability to tropical cyclone and cyclone-related risks due to its positioning of tracks and higher frequency of cyclone landfalls. The geographical alignment places Rakhine State directly in the path of cyclones originating in the Bay of Bengal. Geomorphology of Gulf of Mattaban enhances flood disaster due to river flooding related with torrential heavy rains and tidal bores.



(a) (b)

Figure 7: Flood inundation extent (a) comparison of inundation depth (b) Flooded area of cyclone Nargis by NASA (Flooded areas are indicates with blue, cities with red, and tree cover appear in shades of green (dense tree cover) to pale yellow (spare tree cover)

1.3. Tsunami

Myanmar is located one of the major seismic belt- the Alpide Belt (situated in the southern part of the Himalaya and the eastern margin of the Indian Ocean) and is an earthquake prone zone itself due to the active Sagaing fault, and the Sunda subduction megathrust zone. There were records of moderate tsunami generated by two large magnitude earthquakes which originated in the Andaman-Nicobar Islands (these are 31 December 1881 Car Nicobar Earthquake (M 7.9) and 26 June 1941 Andaman Island Earthquake (M 7.7) [34]. The giant December 26, 2004 Sumatra Earthquake (Mw 9.1–9.3) also caused some damages along Ayeyarwady delta and Taninthayi coast with 71 casualties. The tsunami wave height was between 0.4 and 2.9 m and the tsunami arrival times were mostly between 9:30 and 13:00, that is 2 to 5.5 hours after the earthquake along the Myanmar coast as reconstructed with post Tsunami survey data as shown in Figure 8 [32]. According to author’s field survey, there were no infrastructures for protection of tsunami hazard along Myanmar coast and the tsunami hazard would be more critical for nearby tsunami sources.

1.4. Coastal Erosion Along Myanmar Coast

Coasts are dynamic environments shaped by ongoing natural process such as sediment deposition or erosion,

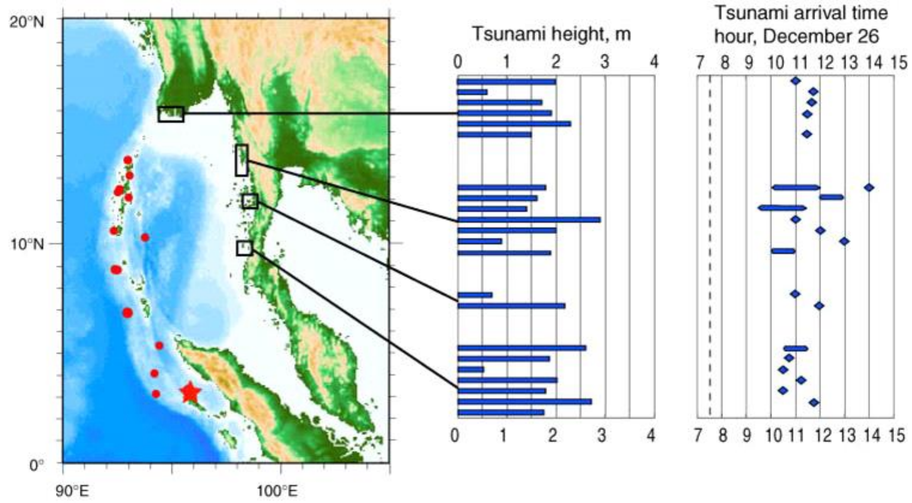


Figure 8: Tsunami Survey Data [32]

usually by wind, wave, current and; sea level rise in the long run. This process may be pronounced during extreme weather events such as tropical storm(cyclones) by mean of flooding and erosion along the coast and risk to people, infrastructures, and ecosystem. Increasing climate changes (temperature and natural disasters) and human activities such as sand mining and deforestation in Myanmar tend to worsen the coastal erosion and coastal communities.

As the earlier study about coastline evolution delta region of Myanmar (including Sittaung River Mouth) from 1850 to 2006, Hedley et.al, 2009 found that Ayeyarwady coast line was stable with maximum average propagation rate of 0.34 km per century (3.6 m/year) since 1925 although Chhibber (1934) calculated an average value of 4.8 km per century 48 m/year on the seaward displacement of bathymetric contours between 1860 and 1910. The author [25] and [12] reported that the average propagating rate was 2.5 km per century (25m/year) and 50 to 60 m/year respectively. Between 1925 and 1973, 30.7 km^2 of land gained and 2.1 km^2 was lost, and between 1973 to 2006, 10.3 km^2, was apparently gained and 7.1 km^2 was lost. The author [11] analyzed the shore line and land use changes of Ayeyarwady delta between 1974 to 2014 and evaluated that erosion and accretion has occurred of more than 10m/year on average and mangrove area significantly drop during these periods. Her finding agreed with the author [2] who conducted shore line characterized the period of 1974-2019 and the author [6] (1974-2018). Both authors identified that mean overall advance rate was 9.4 m/year +/- 3.9m and 10.4 m/year respectively during the over 40-year periods and western sector of lower delta shore line was more subjected erosion. In the western coast, 60% of shoreline was under erosion with an average shoreline change rate of 0.1m/year. In the east part, 81% of the shoreline was accreted with an average accretion rate of 24m/year [6]. Based on identification of field survey of author [7] and detection of remote sensing technique using DSAS tool [3], erosion along the coast was affected up to 150 m in places and some hot spots reach over 1 km during the cyclone Nargis (between April 18 and May 4).

Gulf of Mattaban coast is well known for its powerful tidal bore phenomenon and unique hydro-morphodynamical behavior (rapid channel migration). The dynamics of the tidal channels in the Sittaung estuary result in severe coastline regression, especially at the head of the Gulf, at immense rates and over large distances with more than 5 m/day or 1 km/year at some locations of Bago coast (Acadis). The direction of the migration and the erosion does change in periods of 10 to 15 years in the southern part of the estuary. The erosion rate reached as high as 3 km/yr in some places, and small villages of rice farmers adjacent to the estuary have been gradually abandoned [27]. According to the remote sensing study and field survey, the erosion area at the east side of the river is about 15.7 percent of the whole erosion area and the west side of the river is 84.3 percent. The deposition area in the eastern bank is about 70 percent of the whole deposition area whereas the western side is about 30 percent (MMU students, 2019, not publish).

As the recent study of coast line characteristics change of Main land South-East Asia region for the period of 2000-2015 by the author [26], reclamation coastline variation was increasing 25.92 km to 127.69 km mainly in Gulf of Mattaban; follow by aquaculture dike (3.19 to 11.26 km) and urban area (44.24 to 51.67 km) along the coastline of Myanmar. Mid Rakhine coast had rising trend of fractal dimension and follow by GOM. Two hot spots in Myanmar, the coastline expanded and retreated at maximum rates of 640.85 and -807.85 $m.a^{-1}$ along the coast from the Gulf of Martaban to the Ayeyarwady Delta (17.11 m/y mean acceleration and -8.24 m/y mean erosion); 593.61 and -261.69 $m.a^{-1}$, respectively, along the northern coast of Rakhine State. Sothern coast of Rakhine and Tanintharyi coast line was generally defined invariant coastline according to author [26] and shown in Fig 9. Ayeyarwady Delta and northern Rakhine State are typical regions where coastlines have been enclosed toward sea for agriculture cultivation and have retreated toward land, induced by storm surge and diminishing mangroves.

The estimates of the rate of change of coast line are very variably due differences in temporal and spatial scale of studies, the dataset used, methods and purposes of the study. However, each author has highlighted the potential for reduced sediment supply caused by factors such as damming upstream of rivers, sand mining, extensive deforestation driven by land use changes, and the increasing risk of climate change-induced natural disasters. These factors primarily underscore the vulnerability of Myanmar's natural coastline positioning.

1.5. Sea Level Rise

In order to examine the response of particular coastal system, current and predicted sea level changes need to be considered. Sea level has been rising at an increasing trend due to the thermal expansion of water associated with the warming ocean and the melting of glacier and ice [9] around the globe over the last century, With the positive trend in global warming, estimated global mean sea level rise from satellite altimetry is to be 3.2 mm yr^{-1}but is far from uniform across the globe.

The Department of Meteorology and Hydrology (DMH, 2016) of Myanmar describes that coastal and delta region have an average maximum temperature of 32°C increased by 0.23°C per decade. Regional sea level changes are strongly affected by ocean warming, ocean dynamic responses, and gravitational and solid earth

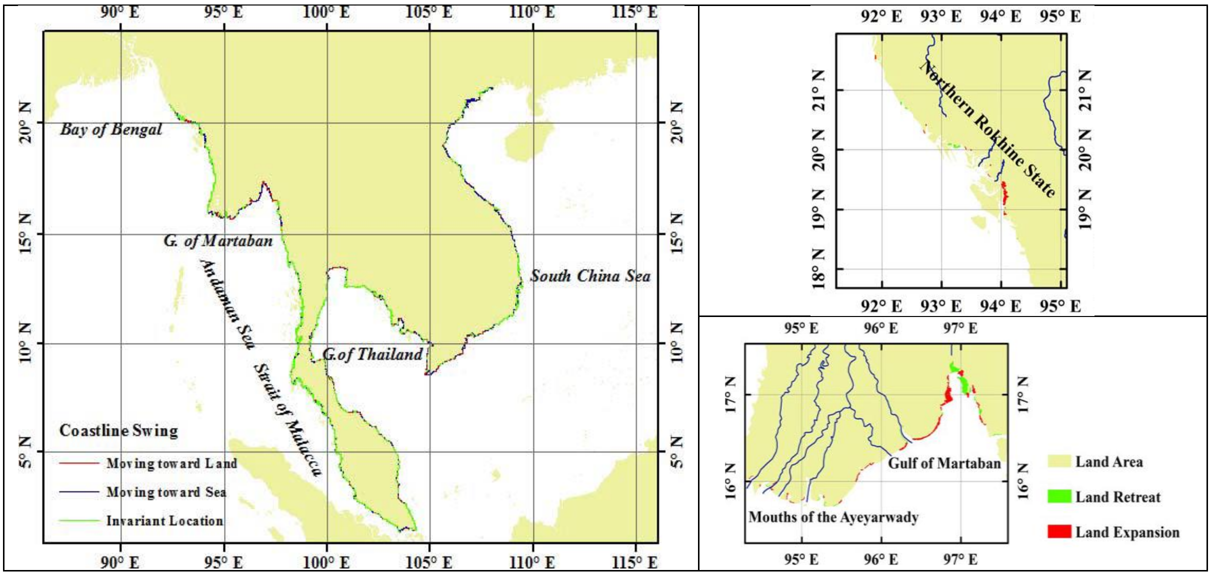
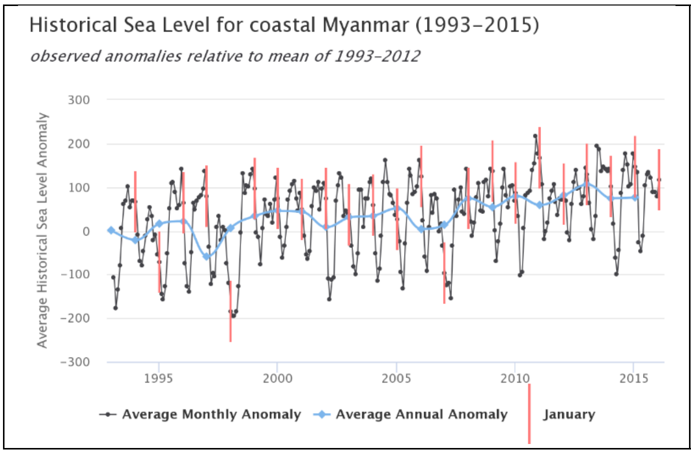


Figure 9: (a)Pattern of coast line in MSA and (b & c) Land-sea interchange of northern Rakhine State and Delta [26]

effects from changing surface mass [21] & [29]. Tidal gauge data for the delta indicate a 3.4–6 mm/y relative sea-level rise [31]. It is very challenging to calculate sea level rise and propagation with qualitative measurement for specific region of Myanmar coast due to the lack of the long-term sea level recorded data along the coastal region and only recorded at Moulemyine (GLOSS station-global sea level observation system at Kyauk ka mi) which is the zero-level datum or land bench mark of Myanmar.

Rising sea level impacts not only the physical coastline feature but also the coastal ecosystem and severe soil and ground water salinization by sea water intrusion. Projections of sea level rise along with Myanmar's coast range from 5cm to13 cm by 2020 and 20 to 41 centimeters by the 2050s [18]. Projections for the 2080s, ranging from 37 to 83 cm, and they could rise as high as 122 cm [13]. Ministry of Environmental Conservation and Forestry and Department of Meteorology and Hydrology, 2012 has been estimated that a 0.5 m rise in sea levels could cause the coastline to retreat by approximately 10 km in Myanmar’s lowest lying areas like the Ayeyarwady Delta.

Based on the exploration of NOAA historical (satellite measured) sea level anomalies between 1993 to 2015, shown in Fig 10a, upward trend can be noticed and average annual anomaly is increasing 76.18 mm during this period. Projected sea level rise estimated by RCP 2.6, 4.5 and 8.5 for 2008 to 2100 is presented on climate change knowledge portal and shown in Figure 10b. By reference these data, sea level along Myanmar coast rises 0.1 m in 2022 with 50th percentile and can rise maximum 0.26 m in 2050 and 0.74 m in 2100 respectively. Estimated land area flooded for tropical central Asia with a relative sea-level rise (RSLR) of 1 meter by 2100 determined from GLL_DTM_v1 is illustrated in Figure 11[1]. As can be seen the picture, Ayeyarwady delta and middle and southern part of Rakhine coast affect this one-meter sea level rise. Saline intrusion as the signal of sea level rise associated with land surface subsidence and land use/cover changes have been noticed and facing the problem along the low-lying coastal region of Myanmar especially causing the greatest sign of seawaterintrusion to Groundwater and fresh water aquifers at Ayeyarwady delta area in Myanmar and Yangon region [13].



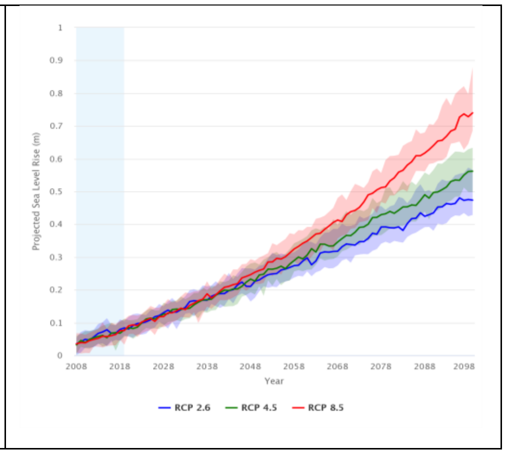


Figure 10a: Historical Sea Level (1993-2015) **Figure 10b:** Project Sea Level Rise for Future

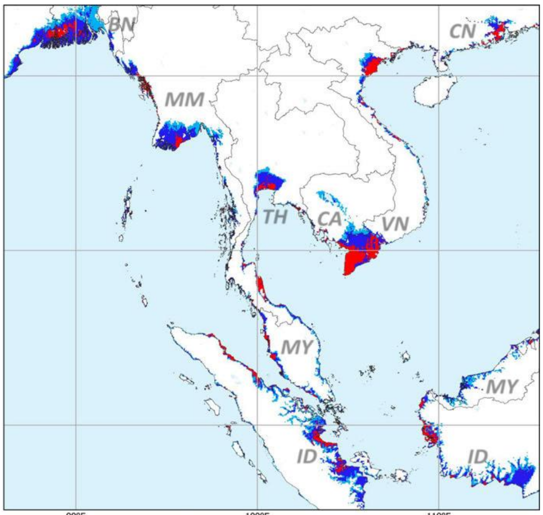


Figure 11: Flooded area with 1m relative sea lever rise [1]

1.6. Anthropogenic Impact

Human migration to the coastal zone and consequent land-use changes have also greatly impacted coastal areas. The economy of Myanmar is largely based on agriculture. Specifically in the coastal region of Myanmar, the livelihood mainly depends on farming and fishing with limited tourism and industrial activities. The human impacts on the coastal zone of Myanmar ranges from massive (e.g., reduction in wetlands, urbanization) to non-existent (e.g., the northern most coastlines). The main drivers are deforestation and degradation of mangroves, over-exploitation of natural resources, poverty, electrical shortage, unsustainable land use, lack of knowledge and awareness of improved resource management techniques, as well as land tenure insecurity which have all contributed to widespread environmental degradation.

In some areas, the coast has been exposed to the ocean as the mangroves which provide a buffer from storm and wave action as well as a filter for sediment have been cleared. The reduction of mangrove areal is either due to over exploitation of firewood and charcoal (legally and illegally), expansion of shrimp farming and fishery related business (fish smoking, drying, fish and shrimp boiling to produce fish & shrimp paste, fish paste and salt), salt mining in salt pans (legally and illegally) or to make room for more rice production or tourism development and environmental pollution and climate change. Furthermore, excessive and unregulated sand mining along sandy coastline and upstream of the tributaries in combination with sea level rise could be the serious concern as the erosion of the coastline for the long term. Sand mining along the coastal region and river bank of Myanmar is presented in Figure 12. Lastly, the mangrove has also disappeared due to incidences of natural disasters (cyclones). Figure 13 shows the destruction of mangrove forests in Cyclone Nargis.

(a) (b) (c)

Figure 12: (a) Truck being loaded with white sand at Ngapali beach (b) Example of sand mining at Sittwe beach (Rammar Kyaw Saw,2022) (c) Example of sand mining using boats in Pyay (Ayeyarwady river)

Figure 13: Destruction of mangrove forests in Cyclone Nargis at MainmaHla Island

1.7. Discussion

This comprehensive review highlights that the coastal zone of Myanmar is subject to highly complex and dynamic natural processes driven by seasonal monsoon variability, wave climate, storm surges associated with tropical cyclones, sea-level rise, and geomorphological change. The coastline of Myanmar, spanning the Bay of Bengal and the Andaman Sea, is strongly influenced by the southwest monsoon (May–October) with higher energy conditions and the northeast monsoon (November–February) with milder wave energy. Several modeling efforts using tools such as SWAN, DOLPHIN, and WAVEWATCH III have improved our understanding of Myanmar’s wave climate, with findings broadly agreeing that wave heights are roughly twice as high during the southwest monsoon compared to the northeast monsoon. However, some contradictory evidence remains regarding the wave spectrum (single-peak versus double-peak), pointing to an ongoing need for robust in-situ wave measurement and validation.

Myanmar’s coastal areas are highly vulnerable to tropical cyclone impacts. Historical data shows 19 cyclone landfalls along the Myanmar coast in 45 years, with the Rakhine coast most frequently affected. These cyclones, especially when coinciding with high spring tides, create severe storm surges, as seen in the devastating Cyclone Nargis of 2008. Combined with semi-diurnal tides, large tidal ranges, and shallow bathymetry, the risk of coastal flooding and erosion is significant. Modeling efforts of flood inundation have been limited by coarse-resolution data, restricting the precision of risk assessments.

Long-term coastal change in Myanmar is shaped by the interplay of sediment transport, river discharge, and human interventions. Several studies have documented both shoreline accretion and erosion in the Ayeyarwady delta and along the Gulf of Martaban, influenced by river sediment dynamics, deltaic processes, and wave forcing. However, growing anthropogenic pressures including mangrove deforestation, unregulated sand mining, upstream damming, and land reclamation have accelerated erosion and destabilized natural sediment balances.

Sea-level rise is another growing concern, with satellite altimetry and tidal gauge data suggesting a relative sea-level rise of around 3.4–6 mm/year along the Myanmar coast, consistent with global projections. Rising seas, coupled with land subsidence and climate-induced extreme events, threaten to displace populations, increase soil and groundwater salinization, and degrade fragile ecosystems such as mangrove forests.

The socio-economic vulnerability of Myanmar’s coastal zone is compounded by poverty, poorly regulated land use, lack of robust environmental governance, and limited scientific monitoring infrastructure. Critical coastal ecosystems notably mangrove forests continue to decline due to unsustainable practices, further reducing natural coastal resilience against storms, flooding, and sea-level rise.

Overall, the synthesis of diverse studies underscores the significant knowledge gaps in Myanmar’s coastal systems. Limited observational data, sparse oceanographic research, and inconsistent measurement records hamper the ability to fully understand and manage the coastal hazards facing Myanmar. There is a pressing need for investment in long-term monitoring networks, high-resolution coastal modeling, and integrated coastal management strategies that can accommodate both natural and human-induced drivers of change.

1.8. Conclusion

Myanmar's coastal zone is facing serious, multidimensional threats from seasonal wave variability, tropical cyclones, storm surges, shoreline erosion, and sea-level rise, compounded by intense human pressures. Historical studies and recent numerical models consistently identify a highly energetic wave climate during the southwest monsoon, significant cyclone-induced flooding risks, and widespread evidence of shoreline change, with rates of erosion and accretion varying greatly across spatial and temporal scales. However, knowledge gaps remain due to limited in-situ data, low-resolution topographic data, and insufficiently validated modeling approaches.

Rising sea levels, projected to reach up to 1 meter by 2100, combined with subsidence and saltwater intrusion, pose serious long-term threats to livelihoods, freshwater resources, and critical infrastructure, especially in low-lying regions such as the Ayeyarwady delta. Human activities, including mangrove clearance, unregulated sand mining, and unsustainable land-use changes, further weaken the natural resilience of these coastal systems.

To address these challenges, future efforts must focus on establishing comprehensive and continuous observation programs, improving numerical models with better ground-truth data, and enhancing community-based coastal adaptation and disaster risk reduction strategies. Strengthening governance, enforcing sustainable resource use, and rehabilitating natural buffers like mangroves will be essential steps toward increasing the resilience of Myanmar's coastal zones against both current hazards and future climate-related threats.

Furthermore, the human-induced acceleration of climate change leading to more frequent storms, coupled with human-induced activities such as sand mining and deforestation, exacerbates the threat of coastal erosion and places coastal communities in Myanmar. Rising sea levels have multifaceted impacts, affecting not only the physical coastline but also the coastal ecosystem and soil and groundwater through salt intrusion to Myanmar coastal region. Human impacts on Myanmar's coastal areas vary significantly, ranging from severe, such as the loss of wetlands and urbanization, to less pronounced contributed to widespread environmental degradation. The Myanmar coast has numerous uncharted areas, with limited oceanographic research due to logistical difficulties, no historical data survey record, low scientific interest, and funding constraints. This lack of research in specific locations results in inadequate knowledge, hindering effective problem-solving for the region and natural resources use and conservation.

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