VULNERABILITY ASSESSMENT OF MANGROVES AND CORALS TO CLIMATE CHANGE AND ITS IMPACT IN

ANDAMAN ISLANDS

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CERTIFICATE FROM THE SUPERVISOR

This is to certify that the thesis entitled "**VULNERABILITY ASSESSMENT OF MANGROVES AND CORALS TO CLIMATE CHANGE AND ITS IMPACT IN ANDAMAN ISLANDS.**" submitted by Mrs Sayani Datta Majumdar who got registered (registration no. **D-7/ISLM/88/18**, dated **January 08,2019**) his/her name under the Faculty of Interdisciplinary Studies, Law & Management for the award PhD (Arts/Science/Engineering/Pharmacy)degree of Jadavpur University, is absolutely based upon his/her own work under the supervision of **Prof. (Dr.) Sugata Hazra** and that neither his/her thesis nor any part of the thesis has been submitted for either any degree/diploma or any other academic award anywhere before.

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I, **SAYANI DATTA MAJUMDAR** (Reg no. **D-7/ISLM/88/18**) registered on **January 08,2019** do hereby declare that this thesis entitled" **VULNERABILITY ASSESSMENT OF MANGROVES AND CORALS TO CLIMATE CHANGE AND ITS IMPACT IN ANDAMAN ISLANDS.**" contains literature survey and original research work done by the undersigned candidate as part of Doctoral studies.

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This work is dedicated to my parents

Late Mrs. Sukla Dutta Majumder and Late. Mr. Anup Kumar Majumdar

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SAYANI DATTA MAJUMDAR

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1. Biophysical vulnerability assessment of coral and mangroves of Andaman Island
2. Social vulnerability assessment of Andaman Islands
3. Status of tourism and scope of sustainability in Andaman Islands.

ABSTRACT

Corals and mangroves, as well as tropical rainforests, are incredibly productive and diverse ecosystems. Tropical and subtropical ecosystems, while facing challenges from extreme weather, rising temperatures, increased sea levels, changing monsoonal patterns, and fluctuations in salinity, demonstrate remarkable resilience. To support their continued vitality, it is essential to proactively address the ongoing degradation driven by natural and human activities. We can reduce the effects of rising sea levels (SLR), especially in vulnerable places like the Bay of Bengal Sea, by using adaptive strategies and helping these important ecosystems thrive in the long run.

The eastern coastal tracts of India and the Andaman Islands, with their micro-tidal characteristics and lower sediment input, require focused attention to mitigate vulnerability. While the northern part of the Bay saw minimal temperature changes in the early 20th century, forward-looking projections suggest a rise in ocean temperatures up to 3.5°C by the end of this century. This presents an opportunity for researchers and policymakers to explore adaptive strategies to manage the anticipated changes. Moreover, the rising acidity of seawater poses a challenge for coral reefs, impacting the formation of corals' exoskeletons. Proactive measures must be implemented to protect these vital ecosystems and enhance their resilience, as it is predicted we could see a decline in coral reefs over the next 50 years if no action is taken. Additionally, ensuring the sustainability of fish populations as they adapt to warmer waters is essential, along with addressing the anticipated 25% decrease in rainfall by 2050 linked to global warming and climate change. These alterations in rainfall patterns call for strategic initiatives to bolster the growth, productivity, and diversity of mangroves, which play a crucial role in coastal ecosystems. By working collaboratively to address these challenges, we can foster a more resilient environment and secure the future of the GBM delta and its diverse habitats.

The Andaman and Nicobar Islands host mangroves and coral, both of which have significant ecological implications. The mangrove ecosystems exhibit resilience to gradual changes, making them less prone to adverse effects of climate change. The

destruction of reefs directly threatens the survival of mangroves, which depend on these ecosystems for essential protection against wave action. It is critical that we prioritize the preservation of coral reefs to ensure the health and stability of mangrove habitats. Decreased rainfall caused by climate change can reduce the growth, seedling survival, diversity and productivity of these vegetation. The corals of the Andaman Islands also face various threats, both natural and anthropogenic, necessitating strategic conservation efforts to protect these vital ecosystems.

The tropical coastal livelihood of Andaman Islands is facing momentous impediments due to global climate change. Their vulnerability is compounded by limited adaptation possibities, such as restricted areas for recolonization, an economy heavily dependent on outside resources, inadequate infrastructure, and a sizable rural population. These factors contribute to high transportation costs and delays in obtaining external supplies, adding to the overall vulnerability of the region. However, by conducting risk assessments and developing comprehensive mitigation plans, the Andaman Islands can better protect their coastal areas and work towards sustainable solutions for their environmental and economic challenges.

The aim of this study was to acquire a thorough understanding of the biophysical dynamics of the Andaman Islands' coastline and the physical phenomena influencing the near-shore coastal waters. Additionally, we carefully evaluated the vulnerability of mangroves, corals, and island communities and quantified the ecosystem services provided by these habitats. Spatial vulnerability models for the mangroves and corals of Andaman Island were developed based on biophysical parameters. Furthermore, an integrated vulnerability framework approach was adopted to appraise the exposure of coastal communities to risks of climate change and their capacity to cope with such risks. Our study aimed to provide perceptions that may contribute to effective monitoring, management, restoration, and prevention strategies It aimed to provide guidance for managing coastal ecosystems sustainably and with environmental awareness, especially considering climate change.

The vulnerability study provided a detailed overview of the probable impacts of SLR, coastal erosion or accretion, land subsidence, rising salinity conditions, and human pressure on mangrove species in the Andaman Islands. The analysis revealed that Mayabunder ranked with very high vulnerability, followed by Diglipur, across almost all exposure and sensitivity components. The study also highlighted the significant adaptation skills of mangroves in Ferragunge and Port Blair, as evidenced by the sufficient regeneration of new mangroves and the development of new mudflats in those areas. Additionally, the study found that North Andaman's mangroves were at greater risk due to various factors, including low species richness, logging, and slow self-regeneration potential. Furthermore, the study emphasized the significant impact of natural and anthropogenic factors on scleractinian corals in the Andaman Islands. It also pointed out the increasing exposure and sensitivity of reefs to climate stressors from North to South Andaman, with Port Blair and Rangat demonstrating high adaptive capacity, particularly through the presence of Marine Protected Areas and a high species recovery rate.

The study's findings emphasized upon the importance of religious efforts for adaptation and systematic planning in reducing social susceptibility to climate change. This research emphasized on continuous monitoring and proper assessment of constant threats such as rise in sea surface temperature, cyclones, and flooding. It underlined that the northern part of Andaman is more socio-economically vulnerable to these risks compared to the central or southern parts of the island. The analysis revealed that areas like Diglipur, with a rural population and a primary focus on agriculture, are more susceptible to natural hazards than urbanized tehsils like Ferrargunj or Port Blair. Micro-scale analysis further illustrates limited water availability, insufficient medical and toilet facilities, and inadequate electricity infrastructure as major threats to the coastal livelihoods of specific regions.

Mangroves and corals in Andaman Island deliver vital coastal ecosystem services, mainly in the form of tourism and fishing. The region's economy is mostly dependent on coastal and marine resources, with fishing being one of the primary industries. Although tourism generates significant revenue, it is highly susceptible to environmental factors and is negatively affected by extreme weather events, which in turn impacts the local livelihoods.

A reliable climate model has been established for the Andaman Region, enhancing our ability to anticipate future coral bleaching events. This forward-thinking strategy empowers us to strategically plan marine and coastal fishery activities and implement effective risk-reduction measures. By addressing the impacts of environmental changes, we can better protect and sustain the reef fisheries of Andaman Island. The findings reveal a promising opportunity to address the concerning upward trend in sea surface temperature (SST) projections under Representative Concentration Pathway 4.5 scenario of the CNRM-CM5 model for the years 2030s, 2050s, and 2060s. This increase in temperature presents a chance for us to focus on proactive measures to mitigate the associated rise in coral bleaching events projected for these decades. By prioritizing conservation efforts and sustainable practices, we can work towards protecting coral ecosystems for the future. Despite previous occurrences of coral bleaching significantly affecting fish catches in the Andaman, particularly for perch species, a steady rise in the exploitation of fish stocks was witnessed. However, the current marine fish stock of the islands represents only 19% of the total available resources, with a production of 30,000 tonnes. By thoughtfully regulating fishers' access to economically significant marine resources—such as edible invertebrates, fish, ornamental species, and decorative shells for tourists—we can promote health of coral reef ecosystems while supporting local livelihoods and tourism.

The study focused on identifying the possibilities of mitigating the negative bearings of over-tourism in the islands. It was found that Port Blair is at high risk of over-tourism, while Diglipur is at low risk, based on various tourism indicators. This highlights the need for targeted interventions in these areas. Additionally, the study shed light on the potential threats to the coral reef ecosystem posed by water-based tourism activities in Port Blair, emphasizing the importance of implementing responsible tourism practices to preserve the marine environment. Furthermore, the study showcased the resilience of the mangroves and corals in South Andaman in comparison to their northern counterparts, underscoring the opportunity to and enhance the adaptive capacity of these ecosystems for sustainable tourism. Thus strategic planning and proactive measures to balance tourism growth with ecological preservation is the call of the hour, particularly in sensitive areas experiencing high tourist demand. This demands for collaboration between stakeholders to ensure that tourism development aligns with environmental conservation efforts for the lasting benefit of the region.

It is imperative to consider how we can minimize the potential negative effects of expected changes in mangrove habitats due to climate change. Efforts to enhance ecosystem resilience and support mangrove rehabilitation can help these habitats withstand and recover from climate-related stressors. Implementation of Marine

Protected Areas (MPAs) and focusing on alleviating threats to coastal livelihoods will play a significant role in building resilience in these ecosystems and communities. The study asserts that in response to ongoing climate change trends, any adaptation schemes or planning should transcend conventional development activities and instead prioritize the establishment of sustainable livelihood practices. This can be achieved through community initiatives and effective governance practices.

Proposed projects in Aves, Long, Smith, and Ross Islands are anticipated to regulate tourist visits to Swaraj Dweep and Shaheed Dweep, as well as other beach destinations, within their ecological carrying capacities, thus safeguarding the islands' eco-system (Niti Ayog, 2019). Additionally, the utilization of artificial reefs is recommended to reduce the physical impact of inexperienced diving at sensitive natural sites. The Exclusive Economic Zone around ANI are rich in fisheries, with tunas constituting three-quarters of them. These untapped oceanic resources remain largely unutilized by local fishers. By introducing a combination of fuel training and boat subsidies, local communities in the Andaman Islands, which have traditionally relied on reef fish for sustenance, can significantly increase their catch by targeting different species. This approach could help reduce their over-reliance on nearshore fishing and promote the growth of deep-sea fishing in the region.

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CHAPTER-1

INTRODUCTION

1.1 Introduction

Climate change represents a profound and enduring transformation in our climate system, emerging over extended timescales, often stretching across decades or even longer. These changes are not merely anecdotal; they can be quantitatively analysed through statistical evaluations of climate characteristics, including averages and their fluctuations. Lot of factors contribute to climate change, particularly those that alter the atmospheric composition and the land (Smith et al.,2014).

Scientific studies estimate that the global air temperature has increased from 0.8°C to 1.3°C from the period of 1850-1900 to 2010, with the most likely estimate being 1.07°C. This rise in temperature can be attributed primarily to greenhouse gases (GHGs). While solar and volcanic activities, have resulted in a temperature rise of roughly ±0.1°C, anthropogenic factor, such as aerosols, have contributed to a cooling effect of about 0.0°C to 0.8°C (Field et al., 2014). Land and ocean sinks have absorbed 56% of carbon dioxide (CO2) emissions from human activities consistently over the past sixty years, though this varies by region. Significant factors contributing to global warming also include halogenated gases and tropospheric ozone (O3). The concentrations of CH4 and N2O are at levels not seen in at least 800,000 years, with a very high degree of certainty. Furthermore, strong evidences indicate that current levels of CO2 have hiked in the past two million years (Cooley et al., 2022). The amount of warming in the future depends on the level of GHG emissions. Higher emissions would lead to greater temperature increases. Current assessments by Cooley et al. (2022) estimate that the range of warming for the period 2081-2100, compared to 1850-1900, varies from 1.4°C if GHG emissions are very low (SSP1-1.9), to 2.7°C to 4.4°C if emissions are very high (SSP5-8.5). It is projected that heavy precipitation and flooding events will intense in regions of North America, Asia, Europe and Africa with a rise of 1.5°C in global temperatures (Cooley et al., 2022). The IPCC AR6 report (2023) further suggests that tropical cyclones and extratropical storms will intensify, alongside an increase in aridity, heatwaves, and droughts.

1.2 Impacts of climate change: Global perspectives

As a result of climate change the geographic range covered by marine species have likely shifted. Since the 1950s, surface temperatures have risen, leading to an average poleward shift of marine species and communities at a rate of 59.2 ± 15.5 kilometres per decade, although responses vary across different taxa and regions. Coastal ecologies like- kelp forests, seagrass meadows and coral reefs, , are at a high risk of undergoing irreversible phase shifts due to marine heatwaves triggered by global warming that exceeds 1.5°C. Even in scenarios where temperatures temporarily rise above 1.5°C, these ecosystems face a significant risk of widespread decline, loss of structural integrity, and transition to net erosion by the middle of the century. Coral reefs, in particular, are especially vulnerable to decline due to the increasing frequency and intensity of marine heatwaves, with very high confidence in these predictions (Field and Barros, 2014).

Climate change presents significant challenges to food and water security worldwide (Vermeulen et al., 2012). While global agricultural productivity has increased over the years, the growth rate has been hindered by climate change in the past five decades. Addressing these challenges offers an opportunity to enhance crop yields, particularly in mid- and low-latitude regions that are experiencing the most significant impacts (Cooley et al., 2022). In relation to our oceans, rising temperatures can lead to reduced maximum catch potential, which is compounded by the issue of overfishing in certain fish stocks. However, this situation also opens up possibilities for innovative solutions in sustainable fishing practices. Ocean acidification and elevated ocean temperatures have affected aquaculture and fisheries in various areas (Cooley et al., 2022), highlighting the importance of adaptive management strategies. Moreover, research by Boesch and Turner (1984) and Roessing et al. (2004) illustrates how change in climate has influenced marine fish species globally. By understanding these changes—such as increased oxygen consumption rates, alterations in physiological and behavioural responses, and shifts in foraging and migration patterns—we can develop effective strategies to support marine biodiversity and enhance fisheries management. Through proactive measures and collaborative efforts, there is great potential to safeguard our food systems and ocean resources for future generations.

Recent evidence indicates that if global warming is restricted to 1.5°C, the mean sea level probably escalates by about 3.0 meters in the next 2,000 years. In contrast, if the increase is limited to 2.0°C, the sea level rise could be between 2.0 and 6.0 meters, although there is low confidence in these predictions. These impacts will threaten coastal ecosystems and the livelihoods of those who depend on them. The ecological consequences of rising sea levels are expected to accelerate rapidly after 2050, particularly in scenarios that combine high emissions with aggressive coastal development. Moreover, recent research suggests that most coral reefs, mangroves, and salt marshes will struggle to keep pace with rising sea levels by 2050, especially if the SSP1-2.6 scenario is followed (Cooley et al., 2022).

1.3 Climate change in the Indian context

Worldwide warming has accelerated by thirty times, leading to an average rise in temperature by 1.0°C as of 2017 (Connors et al., 2019). India is laboriously working to address the impacts of this temperature increase, which include extreme heatwaves, heavy downfall, severe flooding, disastrous storms, and rising ocean situations. These changes are affecting lives, livelihoods, and structure across the country. Recent data indicates that India's mean temperatures have risen by 0.620°C in the last ten decades (Government of India, 2021). Although this increase is slower compared to the global normal, impacts are still being felt. The rise in average temperatures has led to a lower frequency of violent heatwaves, particularly in the western and southern regions, where over 50 of heatwave events passed between 1985 and 2009 (Mazdiyasni et al., 2017; Picciariello et al., 2021). By admitting these challenges, India can apply visionary measures to respond to climate shift, icing safety and rigidity of its communities for the future.

In recent years, the country has encountered several severe rainfall events that significantly impact millions of individuals. Research indicates a relationship between global warming and increase in extreme weather occurrences (Goswami et al., 2006). A rise in atmospheric moisture content, attributed by warming can lead to intensified rainfall (Rajeevan et al., 2008). Studies on, precipitation, evapotranspiration, soil moisture and vegetation indices reveal that nearly 50% of vegetated areas have undergone drying, while only 9% have demonstrated improved moisture levels over the past four decades (Pant et al., 2023). To address these challenges, there is a growing need for innovative strategies in global soil water management (Lal et al., 2023). By focusing on adaptive practices to counter decreasing rainfall, drying soils, and increasing evapotranspiration, we can work towards a bearable future (Piao et al., 2009).

With declining rainfall and increased hard surfaces, soil infiltration and aquifer recharge are severely compromised in India (Picciariello et al., 2021). Agriculture's growing reliance on groundwater is exacerbating the depletion of this vital resource (Zaveri et al., 2016). Consequently, water scarcity affects a billion people for at least a month each year, with 180 million enduring it year-round (Mekonnen and Hoekstra, 2016). The north Indian Ocean has experienced an average rise of 3.2 mm annually between 1993 and 2012, with the Bay of Bengal recording over 5 mm per year (Unnikrishnan et al., 2015). Seasonal sea level fluctuations, particularly during monsoon rains, are leading to extended inundation periods (Arcanjo, 2019), while higher sea levels intensify storm surges and contribute to the increased frequency of cyclones in South Asia. Historically, BoB has been a hotspot for cyclones, accounting for 70% of global casualties from such events last century (Ali, 1999).

Looking forward, climate models suggest India will face an increase of two heatwaves annually, adding 12-18 days of extreme temperatures by 2064. For instance, the hottest month in Delhi could see temperatures reaching 38-43°C between 2071 and 2099 (Kjellstrom et al., 2017). Studies by Swapna et al. (2020) indicate that sea levels along the Indian coast could rise by 20-30 cm, significantly affecting infrastructure and populations in low-lying cities such as Mumbai, Chennai, and Kolkata (Picciariello et al., 2021). Low-income rural communities could also suffer as coastal ecosystems—essential for their livelihoods—face degradation from coral reef loss, mangrove destruction, and saline intrusion into freshwater supplies. Furthermore, the expected doubling of cyclone frequency in the Bay of Bengal by 2070-2100 compared to historical baselines (Sarthi et al., 2014) underscores the dire necessities for adaptive managements against such risks.

1.4 Trends of Climate Change in the Bay of Bengal

. The Bay of Bengal Large Marine Ecosystem (BOBLME) with a total area of 6.20 million square kilometres. is one of the 64 largest marine ecosystems' worldwide, encompassing the territorial seas and entire Exclusive Economic Zones of India, Indonesia, Malaysia, Thailand Maldives, Myanmar, Bangladesh and Sri Lanka. It is the most densely populated LME globally with over 45 crores of coastal population (Barange et al., 2014). Consequently, the threats of altered climate are anticipated to affect the biological systems as well as the communities in this region (Doney et al., 2012). The sea levels have been rising at about 5mm annually in the GBM estuary, according to reports by Antony et al. (2016) and Unnikrishnan and Shankar (2007). Alongi (2008) highlighted that eastern coasts of India along with Andaman Islets are extremely susceptible to sea level hike because of their micro-tidal characteristics and reduced sediment supply. The Sundarbans, continually faces threats from habitat loss, flooding, and land erosion (Payo et al., 2016). Since 1970, approximately 17000 hectares of mangroves have been lost in the Sundarbans region of India and Bangladesh, attributed to rising sea levels, as noted by Rahman et al. (2011).

While the formation of tropical cyclones in the northern part of Indian Ocean is lower compared to other ocean regions such as the Pacific or Atlantic, the shallow coastal waters, flat terrain, and dense populations make the impacts of these cyclones particularly severe when they strike land (McPhaden et al., 2009; Balaguru et al., 2014). The rising frequency of post monsoon cyclones compared to pre monsoon period has been correlated with higher sea surface temperatures (SST) in the North Indian Ocean, alongside increased atmospheric instability (Elsner et al., 2008; Balaguru et al., 2014; Kay et al.,2018).

In the early years of 21st century, northern Bay temperatures did not show significant increases, unlike the southern region, which experienced a rise of 0.2°C (Balaguru et al. 2014). Predictions indicate that by century's end, ocean temperatures may increase by 2-3.5°C. Such warming could result in enhanced stratification, diminished nutrient flow from the depths to the illuminated surface, and an overall decline in biological productivity (Martin and Shaji, 2015). Using historical temperature data and bleaching events, Vivekanandan et al. (2009) assessed the risk to corals in Indian waters, finding that if future temperatures follow the projected path, coral cover is likely to decline significantly. The anticipated frequency of catastrophic events is expected to rise from none during 2000-2009 to ten by 2099, with reef-building corals facing an inability to endure more than three catastrophic events yearly, potentially leading to their decline as prevalent species by 2020-2040 (Vivekanandan, 2010). There are predictions that reefs might vanish between 2030 and 2060, with increasing seawater acidity further hindering coral exoskeleton formation. If acidification continues at its current pace, it is feared that all coral reefs could perish within 50 years. Additionally, warm sea waters may force fish species to migrate from surface waters to deeper depths, as seen with oil sardines, which have expanded from a range of latitudes 8ºN to 14ºN and longitudes 75ºE to 77ºE to a new range of latitudes 14ºN to 20ºN over the last two decades (Vivekanandan, 2010).

The monsoon atmospheric circulation heavily influences the Bay of Bengal, bringing southwest winds and heavy rains in the summer, and northeast winds with less rainfall in winter. This effect surpasses that of the Indian Ocean Dipole or the El Niño Southern Oscillation (ENSO) phenomena. It is projected that rainfall could decrease by 25% by 2050, which may significantly affect the growth, productivity, and diversity of mangrove ecosystems. Mangroves in India and Bangladesh are at considerable risk from reduced freshwater flow driven by changing rainfall patterns, resulting in the gradual replacement of freshwater-dependent mangrove species with salt-tolerant varieties (Kandasamy, 2017; Dasgupta and Shaw, 2017).

1.5 Impact of Climate Change on Small Islands: Observations and Insights

The IPCC AR4 report (2007) highlights the susceptibility of small island nations to climate change impacts. This vulnerability manifests in several ways, including limited access to freshwater and arable land, increased food scarcity, and diminishing energy resources (Mánez et al. 2012). Nations such as Tuvalu and the Maldives, which are at a precarious low elevation of under 2 meters above sea level, face significant threats SLR (Brown et al., 2023).

The effects of altered climate are evident across various natural and human systems, with small islands increasingly suffering from severe environmental events. These include a rise in intensity and incidence of tropical storms, storm surges, droughts, altered precipitation patterns, alongside SLR, coral bleaching, and the spread of invasive species (Spatz et al., 2017). Such climate-driven changes are expected to have profound impacts on both marine and terrestrial ecosystems, creating a domino effect that disrupts both natural and human systems. There is a strong agreement among experts that alterations in wave climate, combined with SLR, are likely to increase the incidence of coastal flooding. While there is limited evidence and medium consensus regarding the erosion of low-lying coastal and reef islands, the trend points towards significant risk (Mycoo et al., 2022; Bellard et al., 2013). If ecosystems are unable to adapt effectively to SLR, coastal flooding is projected to worsen by 2050 (Mycoo et al., 2022). Adaptation strategies and mitigation efforts will be crucial for the resilience of these vulnerable island nations.

1.5.1 Impact on Coral reefs and Coastal ecosystem

Coral reefs are vital for the sustainability of small tropical islands, significantly impacting the livelihoods of island communities. These reefs not only contribute to sediment provision, which mitigates foreshore erosion by breaking wave energy, but they also provide essential habitats for various marine species that many islanders rely on for food (Nurse et al., 2014). Additionally, coral reefs support tourism and economic activities linked to beach and reef ecosystem (Bell et al., 2011). Research indicates that thermal stress directly impacts coral calcification, potentially causing regional declines in coral populations critical for reef structure (De'ath et al., 2009; Tanzil et al., 2009). The Phoenix Islands of Kiribati witnessed catastrophic bleaching, with reports of near-total coral mortality during the 2002-2003 events, severely affecting the outer slopes of Kanton Atoll's reefs (Alling et al., 2007).

Degradation of reefs bears significant consequences for the fisheries, which are essential for local economies and food security. For instance, 65% of coastal fish rely on healthy reefs at some life stage, and their populations have declined due to habitat loss at Kimbe Bay, in Papua New Guinea (Jones and Trevena,2005; Bell et al., 2011). Furthermore, anomalies in SST disrupt the supply of fish larvae from coral reefs, while higher temperatures adversely affect the spawning of adult reef species (Munday et al., 2009; Lo-Yat et al.,2011). Climate change is also causing fishes to migrate to more favourable conditions, which impacts the distribution and species diversity in coastal regions and increases their susceptibility to diseases (Mohanty et al., 2010).

Similarly, mangroves and seagrass ecosystems provide critical services akin to those of reefs (Polidoro et al., 2010). Mangroves are important for both commercial and subsistence purposes and offer natural protection against coastal erosion and storms

(Krauss et al., 2010; Waycott et al., 2011). However, rising sea height poses a significant threat to mangroves, as observed in Hungry Bay, Bermuda, where rising waters are eroding the sea facing edge of the forests (Ellison, 1993). The ability of sedimentation to keep up with changing sea level varies across different regions, as discussed by McKee et al. (2007). Overall, it is evident that changing climate poses a multifaceted menace to reefs and associated networks, necessitating urgent action to safeguard these vital resources for future generations.

1.5.2 Impact on Coastal Settlements and Tourism

In the Pacific, the trend of establishing settlements on high islands has shifted significantly under the influence of colonial, religious, and tourism-related pressures, leading to a concentration of development along coastal lowlands. This structural transition has heightened the vulnerability of populations and infrastructure to natural calamities, rising ocean surfaces and other environmental hazards (Walsh et al.,2012). Atoll Islands, predominantly developed along coastlines, are particularly susceptible, jeopardizing vital resources like fresh groundwater and agricultural areas. As urban centers expand and accommodation becomes limited, individuals are increasingly forced to relocate to areas that are geologically and environmentally at risk (Duvat,2013). This issue is compounded by the migration of populations from outer islands and inland regions, leading to a dangerous cycle of vulnerability. Engineering solutions, such as shoreline reclamation, can exacerbate these risks if they are inadequately planned and resourced (Yamano et al.,2007).

Moreover, the phenomenon of "coastal squeeze" presents further challenges, as necessitating physical development conflicts with the need for ecological preservation. Intensifying coastal development amidst rising population and tourism pressures has resulted in a concentration of both people and infrastructure in at-risk coastal regions (Fish et al.,2008; Mycoo,2011).

Tourism remains a critical economic driver for many small islands, but it faces significant challenges stemming from climate change. The degradation of essential natural resources, including beaches and coral reefs, diminishes the attractiveness of these destinations (Uyarra et al.,2005; Schleupner,2008). This erosion and coral bleaching have been documented in various locations, impacting not only the ecosystem but also the finances of tourism operators and resorts reliant on dive tourism (Gossling et al.,2012). As beach erosion affects accommodation costs, many nations have begun to invest in restoration measures such as artificial seaside nourishment, mangroves and reef rehabilitation, as well as establishing marine protected areas (Houston,2002, Buzinde et al.,2010; McClanahan et al.,2008 Mycoo and Chadwick,2012). The scarcity of freshwater resources, exacerbated by climate change, further complicates tourism operations, pushing many places to adopt desalination plants as a strategy to ensure a steady supply of water. Overall, talking about these multi-layered challenges is crucial for the sustainable tourism in small island settings (Nurse et al.,2014).

1.5.3 Impact on small island's economy

The challenges faced by small island states in terms of economic and environmental vulnerabilities have been extensively studied by researchers such as Briguglio et al. (2009) and Bishop (2012). These islands often experience economic vulnerability due to their significant exposure to external economic conditions, which can largely impact their stability. By diversifying their range of exports and reducing reliance on essential imports like food and fuel, these states can mitigate some of these risks (Briguglio et al., 2009). Moreover, many small islands depend on a few key sectors, such as tourism, fisheries, and agriculture, all of which are sensitive to climate change. Emphasizing climate change adaptation strategies will be essential for maintaining social stability and economic vitality. While government adaptation efforts can be challenged by financial constraints, innovative funding models and partnerships can help overcome these obstacles (Nurse et al., 2014).

Coastal fishing communities, which get severely affected by SLRs and extreme weather, have opportunities for resilience through community-based initiatives. As noted by Nicholls and Cazenave (2010), proactive measures to address these risks can foster more sustainable practices. For instance, Akaba and Akuamoah-Boateng (2018) point out that by investing in protective infrastructure and resilient fishing equipment, communities can safeguard their livelihoods and enhance food security, especially for those most at risk. By taking these constructive steps, small island states can build greater resilience against both economic and environmental challenges.

1.6 Impacts of climate change in small islands: Andaman Island context

The ANI are facing significant risks due to climate change. This impact exacerbates the existing vulnerabilities of the islands and their communities, thus posing difficulties in predicting the exact nature of climate-related events. The ANI is particularly at risk because of its isolated and remote location, which contributes to high transportation costs and delays in accessing external supplies.

Additionally, the islands have limited human and natural resources, an increasing population, and a concentration of productive assets, which hinders the development of diversified economies and increases overall vulnerability (A&N Islands Action Plan on Climate Change, 2013). Lifelines such as communication and transportation are severely affected during natural calamities, complicating the movement of people, which contrasts with what is typically possible on the mainland. During extreme weather events, travel by sea becomes difficult, and homes and infrastructure are at risk of damage from strong winds (A&N Islands Action Plan on Climate Change, 2013).

1.7 Scope of the present research

The rainfall patterns in the Andaman and Nicobar Islands are undergoing significant changes, with a clear departure from historical trends in seasonal distribution. These alterations are directly linked to shifts in global sea levels, leading to a marked increase in the frequency of heavy and extremely heavy rainfall events—rising from an average of 6.5% to between 6.5% and 8.8% during the period from 2013 to 2016. This trend unequivocally demonstrates that heavy rainfall is no longer confined to the monsoon season; rather, it is now occurring with greater frequency during the pre-monsoon and post-monsoon periods, substantially enhancing the predictability of flooding incidents associated with intense precipitation.

The Andaman-Nicobar Islands are situated within the Andaman Basin, a geologically active zone that extends from Myanmar to the Indonesian Islands. This region, located along the Alpine Himalayan belt, is seismically active and has a well-documented history of significant earthquakes, including the catastrophic Mw 9.3 earthquake in 2004. This seismic event not only caused drastic geological shifts in the islands but also triggered massive tsunamis that devastated extensive mangrove areas. The consequences of such events are profound, resulting in critical alterations to ground elevation and the creation of erosion zones that threaten coastal ecosystems.

The aftermath of the 2004 earthquake led to a sharp decline in coral cover, with a staggering 30% loss in the northern regions and 20% in the southern regions due to the combined effects of subsidence and uplift. These geological and climatic shifts present formidable challenges to the resilience of coastal ecosystems, emphasizing the urgent need to address the vulnerabilities faced by the Andaman and Nicobar Islands.

1.7 .1 Threats to Andaman marine ecosystems to climate change

The Islands showcase two critical bionetworks: mangroves and coral reefs, both possessing essential ecological roles. Mangrove ecosystems are particularly notable for their flexibility to the gradual effects of changing climate making them less vulnerable compared to other ecosystems. Nonetheless, damage to coral reefs can have indirect repercussions on mangroves, as these plants depend on reefs for protection against wave action. The impact of climate change, especially through reduced precipitation, threatens to diminish mangrove productivity, seedling survival, overall area, and biodiversity (Srivastava, 2012). The economic implications of mangrove damage are profound, potentially resulting in decreased incomes for fishermen, loss of commercial fisheries that depend on mangroves, and a decline in habitats supporting diverse species such as mollusks, crustaceans, reptiles, birds, and monkeys. Furthermore, the degradation of mangroves can jeopardize coastal safety and development, given their role as a natural buffer against natural disasters (Srivastava, 2012).

Coral reefs in the Andaman Islands also face multiple threats, both natural and human-induced. Natural disturbances like coral bleaching, earthquakes, and tsunamis, along with anthropogenic issues such as siltation, sand mining, deforestation, unsustainable fishing practices, pollution, waste disposal, and tourism, contribute to the decline of these vital ecosystems (Jeyabaskaran, 2007). Moreover, LULC analysis between 1993-2010 revealed that approximately 84.7 square kilometres of mangroves and 50.6 square kilometres of coral reefs have been lost, indicating a critical need for conservation efforts (Fig 1.7.1)

1.7.2 Threats to mangroves

The Forest Survey of India in their 2018 report stated that the Andaman Islands have gradually lost timber cover over time due to the swell and various mortal-convinced problems, including logging. From 2011 to 2018, the area covered by timber dropped from 7,171 square kilometres to 6,742.78 square kilometres. The FSI assessment from 2015 also revealed that the 2004 swell destroyed 3.50 % of the mangrove regions in the islands, with a fresh 2.7 % loss between 2005 and 2015. analogous losses are common in coastal areas along the Andaman Sea (Veettil et al., 2018).

Mangrove timber logging is linked as one of the primary causes of reduction in North Andaman Islands, in distinction with the middle and southern regions. The North Andaman area, being at an advanced elevation, is less susceptible to natural disasters like Tsunamis. Still, the dearth of appropriate law enforcement makes the mangroves in the northern part of the Andaman and Nicobar Islands more dangerous than those in other parts of the island (Chakraborty et al.,2019; Veettil et al.,2020).

1.7.3 Threats to Corals of Andaman

According to the IUCN global status, it is imperative to recognize the serious threat faced by 129 species of scleractinian corals found in India. Out of these species, 118 are classified as vulnerable, 10 are endangered, and one is at imminent risk of extinction. The Acroporidae family stands out with the highest number of vulnerable species, totaling 50. Additionally, two species from the Pectinidae family fall into the vulnerable category. Among the endangered species, the Mussidae and Poritidae families each consist of two species, while Fungiidae, Merulinidae, and Pocilloporidae are represented by one endangered species each, underscoring the urgent need for conservation efforts, as highlighted by the study conducted by Mondal and Raghunathan in 2018.

The catastrophic undersea earthquake on 26th of December, 2004, generated a Tsunami in the north east and south eastern part of Indian Ocean that caused significant geographical shifts, with segments of North and Middle Andaman moving south-westward, and the North Andaman landmass being raised, profoundly altering local ecosystems (Bahuguna et al., 2008; Majumdar et al., 2018).

An increase in sea surface temperature in the Andaman Sea resulted in widespread bleaching, affecting 65%-80% of live coral cover during significant events in 2005 and 2010. The 2010 ENSO phenomena further intensified this threat, resulting in the loss of approximately 70% of live coral in various locations (Fig 1.7.3). Moreover, the health of the reefs is further compromised by polychaetes infestation, which has been reported to affect Porites corals in several areas, mimicking a fungal disease (Dam Roy et al., 2009; Majumdar et al., 2018). Siltation and smothering are also critical issues in the Andaman and Nicobar Islands, as indicated by Raghuraman et al. (2012). The death of ramose corals in various locations has been attributed to rampant sea erosion and resulting siltation, alongside human activities such as sand mining for construction purposes. This situation demands immediate attention to protect and preserve these vital ecosystems (Majumdar et al., 2018; Raghuraman et al.,2012).

The Andaman group of islands stands out as a remarkable natural landscape, celebrated for its scenic beauty and immense tourism potential, drawing approximately 110,000 visitors annually from both domestic and international markets. However, the impact of tourism has been devastating, particularly on coral reefs, leading to significant degradation (Majumdar et al., 2018). While areas like Havelock and Neil Islands promote eco-tourism with their unspoiled reefs and tranquil beaches, they too suffer from the pressures of heavy tourist traffic throughout the year, further threatening the delicate marine ecosystems. Compounding these challenges, the rapid population growth and development projects across the Andaman Islands have resulted in the mismanagement of waste. Untreated sewage from restaurants, hotels, and households is being dumped in the sea, adversely upsetting the health of coral reefs in locations such as North Bay, Minnie Bay, Snake Island, and Navy Bay (Jeyabaskaran,1999).

Additionally, the region's tropical coastal livelihoods and ecosystems are under severe threat from global climate change. Limited adaptation options—exacerbated by a heavily indebted economy reliant on external resources, inadequate infrastructure, and a large rural demographic—heighten the islands' vulnerability. This predicament is made worse by high transportation costs and delays in accessing essential supplies (Andaman Action Plan on Climate Change,2013).

The coastal landscape is highly susceptible to a variety of risks, including declining fish stocks, low agricultural yields due to changing rainfall patterns, rising sea levels, coral bleaching, pressures from local populations, scarce drinking water, and frequent seismic and climatic hazards (Huges et al.,2017; Nicholls and Cazenava,2010). Consequently, conducting risk assessments and formulating mitigation strategies is critical for safeguarding the coastlines of these small islands. Among the vital coastal ecosystem services in the Andaman Islands, tourism and fishing are paramount. The region's economy heavily leans on its coastal and marine resources, with fishing being a key industry. Despite its economic significance, tourism remains incredibly sensitive to environmental conditions and is increasingly threatened by extreme weather events, jeopardizing local livelihoods.

Given these realities, it is essential to estimate the impacts of climate change on fishing and tourism services while exploring both current and future prospects in the Andaman Islands. A robust vulnerability model, informed by this analysis, can facilitate effective monitoring, conservation, and management of the islands' vulnerable areas. Therefore, it is crucial to assess the vulnerability profile of the islands and prioritize institutional responses to effectively counterbalance these pressing threats.

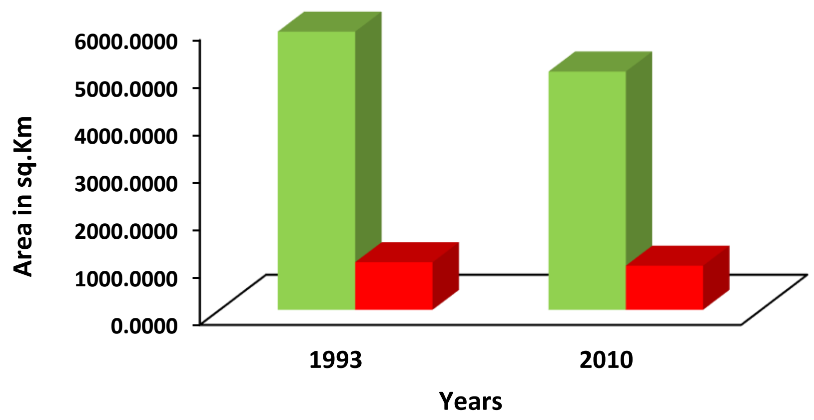


Fig 1.7.1 Assessment of mangrove and coral cover loss due to Tsunami in Andaman Island

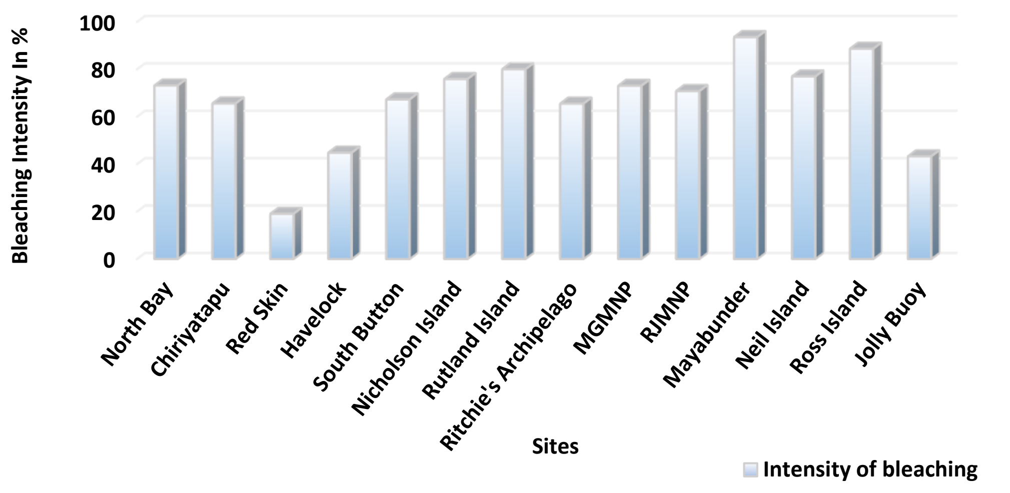


Fig 1.7.3 Intensity of coral bleaching evidenced by different reefs of Andaman Island

1.8 Vulnerability Assessment

1.8.1 Concept

The methods used to evaluate vulnerability vary depending on how vulnerability is defined, the goals of the assessment, and the scales of analysis, including aspects of space, time, and decision-making (Joakim et al., 2016). Since the Third Assessment Report (TAR) by the IPCC in 2001, the scientific communities have placed increasing emphasis on the vulnerabilities and associated risks of changing climatic conditions that can be considered significant due to their magnitude, persistence, and other characteristics. An impact can either be beneficial or harmful. Vulnerability refers to extent by which these systems are prone to negative impacts- their capacity to manage these impacts. The concept of risk involves assessing both the potential impact and the likelihood of its occurrence, taking into account the uncertainty surrounding climate change processes, exposure, sensitivity, and adaptation (Schneider et al., 2007).

Research by Parry & the IPCC (2007), Bennett et al. (2015), Füssel (2007), and McClanahan & Cinner (2011), and has focused on assessing the effectiveness of various coping mechanisms against climate change. Understanding vulnerability is crucial for evaluating the negative outcomes of climate change and identifying strategies so as to alleviate the adverse consequences (Ensor & Berger 2009; Kelly & Adger 2000). The Intergovernmental Panel on Climate Change (IPCC) defines vulnerability as the probability of a system to be negatively affected by climate extremes. This probability is influenced by three factors: the brutality of climate change, the degree of exposure to these changes, and the system's sensitivity and adaptability (Hahn et al., 2009; Schneider et al., 2007; Fritzsche et al., 2014; Ebi et al., 2006). According to the IPCC Fourth Assessment Report, vulnerability is determined by:

Vulnerability = f (Exposure, Sensitivity, Adaptive Capacity) (Das et al., 2020; Hahn et al., 2009

The IPCC's Fifth Assessment Report (AR5) has introduced a new approach and terminology to clarify the concept of risk related to climate change. This new framework differs significantly from the previous understanding of vulnerability found in the IPCC's Fourth Assessment Report (AR4). According to the IPCC AR5, risk is defined as the potential for consequences in situations where something of value is at stake and where the outcome is uncertain, while acknowledging the diversity of values involved. Risk is often represented as the probability of hazardous events or trends multiplied by the impacts these events or trends may cause due to climate change (Field and Barros, 2014). This updated approach provides a more definitive means to address the risks posed by climate change and recognizes the various values affected by it (Oppenheimer et al., 2014).

There are two distinct approaches to defining vulnerability. The first, approach known as the natural hazards school of thought, put emphases on the objective study of environmental risks. Within this, vulnerability is defined as the likelihood of an ecosystem being subjected to a specific environmental stressor. The second approach is rooted in interpretive social science paradigms, which include human ecology and political economy perspectives (Vincent, 2004).

1.8.2 Theoretical frameworks of vulnerability assessment

When evaluating vulnerability, it is essential to consider three key theoretical frameworks: biophysical, social/socioeconomic, and integrated. The biophysical framework relies on quantitative models to gauge the risks and potential impacts that a system may encounter from natural stressors. This method effectively measures both the exposure and sensitivity of biophysical and socioeconomic systems to environmental threats, utilizing climate prediction models and sensitivity indicators for various hazards (Teshome, 2015; Fussel, 2006; Schroter et al., 2004).

In contrast, the social/socioeconomic framework emphasizes the conditions of households or communities within their socio-economic and political contexts. This approach highlights that vulnerabilities often stem from economic imbalances, power disparities, knowledge dissemination, and discrimination regarding social welfare (Adger & Kelly, 1999; Fussel & Klein, 2005; Wisner et al., 2004). Social vulnerability is typically broken down into exposure, sensitivity, and adaptive capacity, each capturing different dimensions of vulnerability (Turner II et al., 2003). Recognizing the limitations of both biophysical and socioeconomic frameworks has led to the development of an integrated vulnerability assessment framework. This comprehensive approach merges insights from various disciplines and acknowledges the interconnectedness of physical, biological, and social systems (Fussel & Klein, 2005; Houghton, 2009). It asserts that natural elements cannot be examined in isolation from their social and economic contexts, reinforcing the necessity of evaluating the interplay between these systems for a holistic understanding of vulnerability (Brooks and Adger, 2003; Luk, 2011).

1.8.3 Biophysical Vs Social Vulnerability

The conception of vulnerability within climate change literature presents a precious frame for understanding the different confines of threat faced by colourful systems. It can be courteously divided into two main orders. The first order focuses on the implicit damage that climate- related events can induce on specific systems, as noted by Jones and Boer (2003). This approach involves assessing hazards and their impacts, but it's important to fete the significant part that mortal systems play in shaping these issues. For case, numerous climate impact studies assess the number of people at threat from flooding due to projected ocean position rise, as stressed by Nicholls et al. (1999). While these studies give pivotal perceptivity into mortal exposure, they frequently profit from a broader examination of communities' capacities to manage with similar hazards.

Assessments informed by the hazards and impacts frame estimate the vulnerability of mortal systems grounded on factors similar as the nature of the physical hazards faced, the liability of these events being, the extent of mortal exposure, and the perceptivity of the system to impacts. This comprehensive approach aligns with the description of vulnerability put forth in the IPCC AR3 report (IPCC, 2001). When combining hazard, exposure, and perceptivity, we arrive at a conception known as physical or biophysical vulnerability, which focuses on understanding the extent of damage from dangerous events, as bandied by Brooks (2003).

In discrepancy, the alternate order invites us to consider vulnerability as an essential condition within systems, as suggested by Allen (2003). This perspective emphasizes that vulnerability can live singly of external pitfalls, stemming from the structural characteristics of mortal societies. numerous experimenters have contributed to our understanding of "social vulnerability" (Adger, 1999), which has come a focal point in field exploration and vulnerability mapping enterprise. By relating the most vulnerable populations and assaying variations in threat within analogous geographical areas, we can develop targeted interventions (Downing and Patwardhan, 2003). Factors similar as inequality, poverty, food security play vital places in determining social vulnerability (Blaikie et al., 1994; Cross, 2001).

To apply effective strategies, social vulnerability can be distributed into three interrelated factors exposure, perceptivity, and adaptive capacity (Turner II et al., 2003). Exposure encompasses the degree of climatic pitfalls similar as hurricanes, famines, cataracts, and storms — that hang the livelihoods of resider's. perceptivity captures how changing climate conditions affect pastoral homes, frequently measured by the frequence of food or water failure and poverty situations. Incipiently, adaptive capacity highlights the capability of individualities and communities to acclimate the climate exposure (IPCC, 2007). Fastening on these factors allows for a more formative understanding of vulnerability, guiding sweats toward adaptability and adaption in the face of climate change.

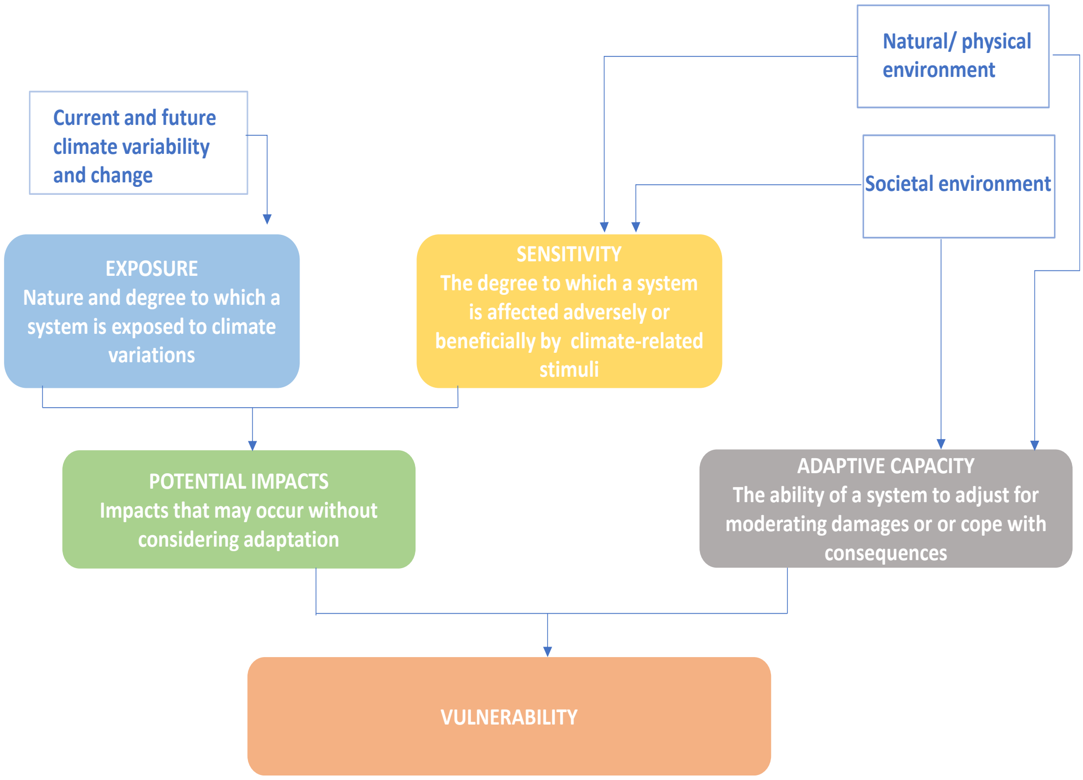


Fig 1.8.3 Vulnerability Assessment Framework based on IPCC Fourth Assessment Report

1.9 Conclusion

The literature has synthesized both global and regional scenarios of climate change, along with various concepts of vulnerability, within a multi-dimensional framework—specifically focusing on climate change. Different scholars have applied varied approaches to assess vulnerability. In this research, we will define and assess vulnerability based on themes from the IPCC. The objective of this study is to assess the biophysical and social vulnerability of the Andaman Islands, aiming to enhance the ability of ecosystems and communities to cope with climate change and climate variability. Given that small island marine ecosystems have significant socio-economic implications for coastal communities, we will modify the vulnerability assessment model to evaluate the susceptibility of these island ecosystems to natural disasters and climate change.

This research aims to provide policymakers with a deeper understanding of local communities' vulnerability to climate change, ultimately leading to better strategies and adjustments that will help these communities adapt more effectively to these changes.

CHAPTER-2

METHODOLOGY OF THE RESEARCH

2.1Introduction

The risks of mangroves, corals, along with the island communities were comprehensively assessed about various environmental factors, including regional sea level rise, climatic conditions, coastal erosion, cyclones, storm surges, coastal flooding, and potential changes in land cover. Additionally, the services provided by the mangroves and corals were carefully documented and quantified. An in-depth study of the social-economic implications of the habitats on the local population was conducted. Furthermore, the vulnerability of the mangroves, corals, and coastal communities to altered climate were quantitatively evaluated utilizing remote sensing and GIS-based spatial and multi-temporal studies. The findings of this research have led to a framework for effective monitoring, management, restoration, and prevention strategies which will establish clear guidelines for future coastal ecosystem management, prioritizing sustainable and environmentally conscious practices.

In the present research to achieve all its objectives, a specific methodological approach was adopted (Fig 2.1). This approach was deemed the most efficient and effective given the available resources. The study focused on the vulnerability of mangroves and corals in the Andaman Islands, as well as their impact on the major ecosystem services provided to local communities. This comprehensive study necessitated extensive data collection to capture the complexity of the subject matter. During field visits, all necessary primary data were logged to support the research objectives. The data collection and analysis were systematically conducted to highlight the variability of parameters across different time frames and spatial scales, ensuring robust and reliable findings.

2.2 Research Problem

The study aimed to recognize the unique characteristics of the marine bionetworks of reefs and mangroves of Andaman Islands and document the significant threats that endanger these two marine ecosystems to climate change. The degradation of marine ecologies of these islands can be attributed to human activities, including unsustainable logging, encroachment for settlement, pollution, coastal development, and the conversion of land for agriculture and aquaculture or temporary effects of the

El Niño-Southern Oscillation, rising sea levels, altered water discharge disrupt the delicate balance of these ecosystems. Understanding the economic benefits and values of these ecosystems is crucial, as is the assessment of how environmental changes might affect ecosystem services such as fishery and tourism, along with other provisioning and regulating services. Mitigation strategies for these potential impacts need to be explored. The spatial vulnerability models based on biophysical parameters were built up for the Andaman Island mangroves and corals while an integrated vulnerability framework approach was adopted whereby the magnitude of exposure of coastal communities to threats of climate change; their ability to cope with such risks was assessed based on social and economic status of individuals, as well as institutional characteristics (Fussel & Klein, 2005).

2.3 Central Queries of the Present Research

- What factors are responsible for the vulnerability of the mangrove–alone ecosystem?
- What are the factors responsible for the social vulnerability of Andaman communities?
- How does the present environmental changes affect the provisioning and regulating ecosystem services like fishery, tourism
- How can such potential impacts be ameliorated?

2.4 Broad Objectives of the Study

- To develop an idea about the status of the mangrove–corals of the study region
- To generate bio-physical vulnerability assessment models of the mangrove-coral ecosystem services to environmental changes
- To generate a social vulnerability assessment model of communities of Andaman to climate and environmental changes
- To develop policy options to manage the degradation of these ecosystems from environmental changes.

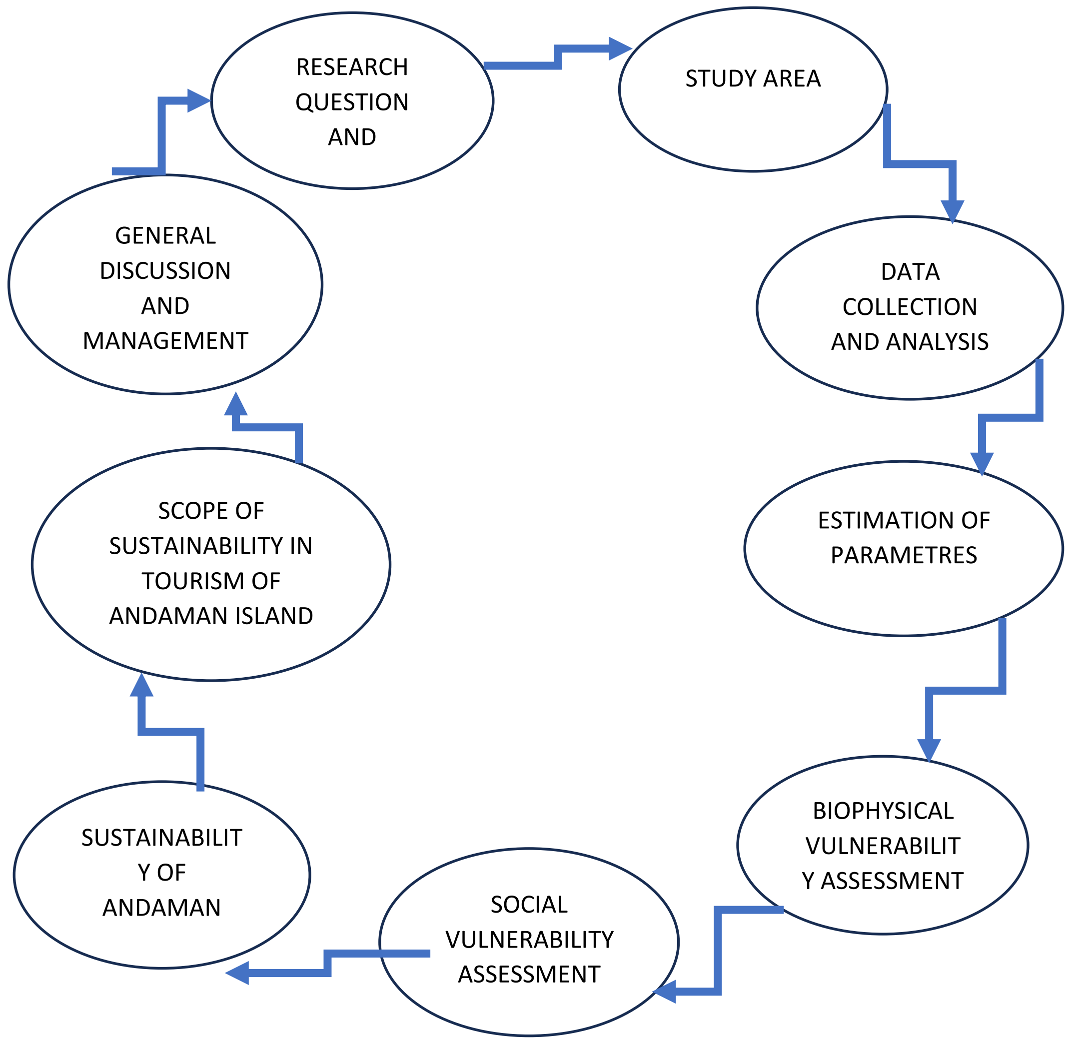


Fig 2.1 Illustration of the research design of the present study

2.5 Biophysical Vulnerability Assessment of Mangroves and Corals of Andaman Island

Climate change is a critical issue that demands urgent attention, particularly concerning the vulnerability of ecosystems. Research demonstrates that various ecosystems, including intertidal mangrove ecosystems and fringing coral reefs, are at risk (Zhao et al.,2007). Vulnerability assessments have been performed by various scholars, and, focusing on the endpoint interpretation of vulnerability (Johnson and Marshall 2007). Understanding vulnerability involves three key dimensions: exposure to climate stresses, sensitivity to those stresses, and adaptive capacity, as highlighted by Polsky et al. (2007). A comprehensive vulnerability assessment, takes into account various parameters to elucidate the processes and outcomes related to vulnerability (Fig 2.5). For regions like Andaman Island, applying this assessment framework is vital for enhancing climate change adaptation planning for both mangroves and corals (Adger,2006).

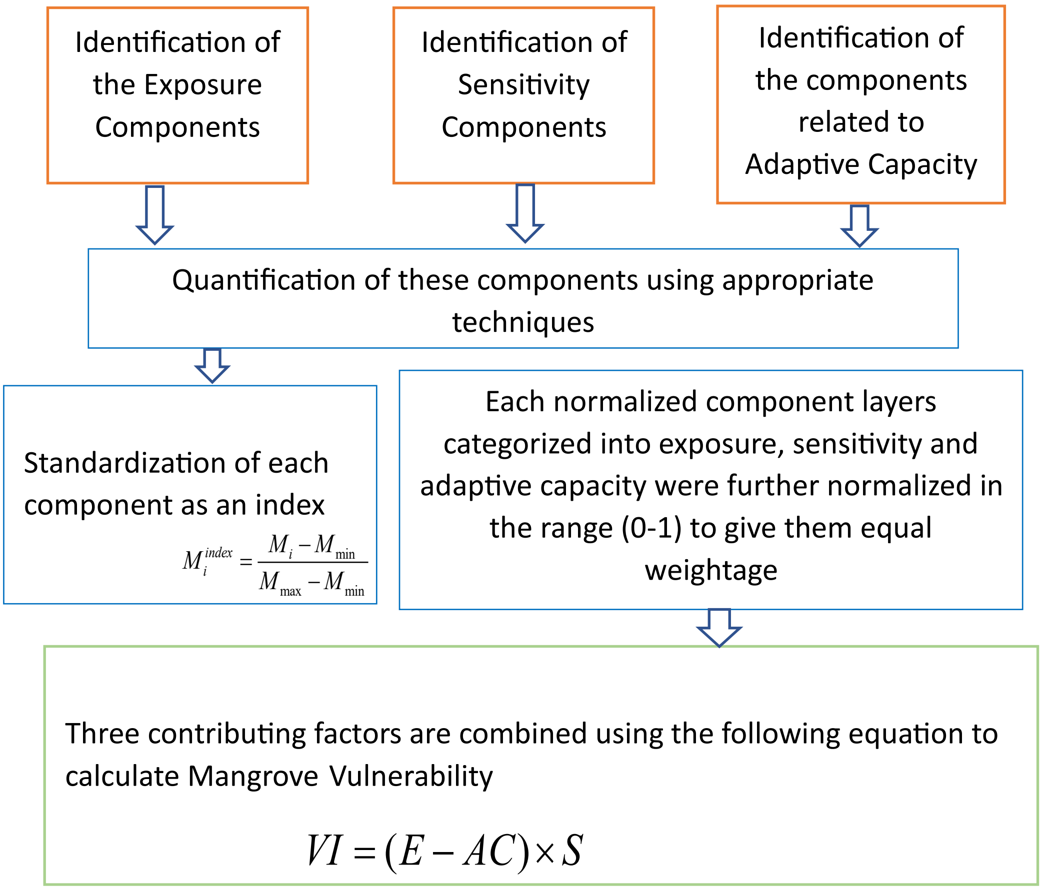


Fig 2.5 Methodological framework of Biophysical Vulnerability Assessment

2.5.1 Components and their measuring techniques

As per Ellison's (2015) studies, seventeen significant bio-physical components were selected and categorised into three factors - Exposure, Sensitivity, and Adaptive Capacity. While the variables under the exposure components were the same for mangroves and corals, the variables under sensitivity and adaptive capacity were different for each ecosystem. These variables include relative and specific humidity, temperature, wind and current speed, precipitation, tidal range, sea surface height, sea surface temperature and wind direction. The sensitivity factors for mangrove vulnerability assessment included mangrove health, elevation, loss of mudflats, reduction in mangrove cover, salinity, and inundation threats to mangroves. Similarly, the sensitivity component for corals included bleaching intensity, temporal decrease in coral cover, and the percentage of corals at risk of inundation. The adaptive capacity of mangroves was determined by looking at the mangrove forest regeneration rate and percentage regeneration of mudflats. In contrast, the adaptive capacity of corals was determined by looking at the coral regeneration rate and monsoon rainfall. (Table 2.5.1). After thoroughly reviewing available literature and primary and secondary data obtained from field measurements, remote sensing products and web portals, we have identified the necessary components related to mangrove and coral ecosystems, and how they are affected by climate change phenomena.

2.5.2 Data Acquisition

Satellite data from multiple sensors were acquired from February 1993 to March 2018. Cloud-free **Landsat 5 Thematic Mapper (TM),** surface reflectance (ρ) product was downloaded from the **United States Geological Survey (USGS) Earth Explorer** website and **Sentinel-1** products, having a high spatial resolution of 10m, were downloaded from the **European Space Agency (ESA) Scientific Data Hub** website, corresponding to Andaman Island for LULC classification, coral cover and flood risk mapping. The combination of these data sources aimed to improve the accuracy of LULC classification and mapping.

Aqua MODIS (Moderate-resolution Imaging Spectroradiometer) 9.26 km spatial resolution Level-3 gridded 8-day average SST products were also downloaded from

Table 2.5.1. Biophysical Vulnerability components and their measuring techniques

Factors	Mangrove Vulnerability Components	Coral Vulnerability Components	Measurement	References
Exposure	Tidal range		Secondary data	Survey of India,2022, Mondal et al.,2024, Sangmanee et al.,2021
	Precipitation	Precipitation	TRMM rainfall data	Kumar et al.,2017, Shrestha et al.,2019
	Temperature		IMD time series temperature data, Future temperature data from available climate projections	Clough et al., 1999, , Cheeseman (1994),Field (1995), Alongi (2008)
	Sea surface temperature	Sea surface temperature	MODIS SST	Krishnan et al. (2011); Mondal et al. (2014)
	Earth skin temperature		NASA AGRO CLIMATE DATA	https://power.larc.nasa.gov
	Wind Speed and Wind Direction,	Wind Speed and Wind Direction,	NASA AGRO CLIMATE DATA	
	Specific and		NASA AGRO CLIMATE DATA	
	relative humidity		NASA AGRO CLIMATE DATA	
	Current speed	Current speed	Frequency and wind speed of storms- Ocean Motion	Semeniuk (1994), Cahoon (2006), Alongi (2008), Faraco (2010)
	Sea Surface Height		Remote Sensing Techniques	Shirayama Y. and Thornton H. (2005), UNDP, 2013
Sensitivity	Mangrove forest health		Forest health assessment using Remote Sensing and GIS Techniques (EVI, NDVI, SAVI, TNDVI etc.)	Wagner and Sallema-Mtui (2010), Fiu et al. (2010),Ajonina and Chuyong (2011), Ajonina et al. (2014)
	Soil Salinity		Field data collected	Ellison and Zouh (2012), Ellison and Strickland 2013
	Elevation		SRTM DEM	
	Erosion and Accretion	Erosion and Accretion	Erosion and accretion mapping using RS GIS techniques.	Fiu et al. (2010), Ellison and Zouh (2012),Punwong et al. (2013), Ellison and Strickland
	Reduction in mangrove area	Bleaching Intensity		Mondal et al.,2019, Krishnan et al.,2013
		Reduction in coral cover	Forest cover change mapping from temporal satellite images.	Ellison and Zouh (2012), Burgess et al. (2013)
	% Loss of mudflat	Corals at risk of inundation	Land use land cover	Ellison and Zouh (2012), Burgess et al. (2013)
	% Mangrove inundated		Flood inundation mapping	Prerna et al.,2015
Adaptive Capacity	Regeneration rate after an extreme event	Regeneration rate after an extreme event	Existing Literature	Turner et al., 2009, Marimuthu et al., 2013
		MPA	Existing Literature	Hu et al.,2022
	MPA			

NASA’s Ocean Colour website. These were used for calibration of sea surface temperature and long-term (2003–2018) seasonal and annual trend analyses.

Additionally, physical-meteorological parameters specific to Andaman Island were incorporated. Monthly averaged precipitation from **Tropical Rainfall Measuring Mission (TRMM)** products and earth surface temperature data from January 1998 to December 2018 were downloaded from **NASA's Giovanni** web-based application interface and averaged by area. In a study conducted by Kumar et al. in 2017, physical-meteorological parameters were used to determine the impact of these variables on the biophysical parameters of Bhitarkanika mangroves. The monthly temperature records for the period 1990-2018 were collected from the Indian Meteorological Department's time series data.

Regional elevation is clearly defined as the height of a location above mean sea level, and it plays a critical role in evaluating areas prone to sea-level rise (Diez et al., 2007). Coastal regions at lower elevations face significant vulnerabilities, while those at higher elevations show less sensitivity to changes. The research employed Shuttle **Radar Topography Mission (SRTM) Digital Elevation Model (DEM**) data, which has a spatial resolution of 30 meters, to determine regional elevation and coastal slope using ArcGIS software obtained from the **United States Geological Survey** (USGS) (https://earthexplorer.usgs.gov/). Notably, the five identified zones exhibit a range of altitudes spanning from 85.0 m to –5.00 m.

The mean tidal range represents the difference between average high and low tides, influenced by factors such as sea-level rise, flooding, and storm surges (Diez et al., 2007). For this investigation, tidal range data were sourced from the Survey of India (2022) and an article by Sangmanee et al. (2021). In this study, areas characterized by low tidal ranges are classified as highly vulnerable (rank 5) (Dwarakish et al., 2008; Gorokhovich et al., 2014), as the water flow in these regions tends to remain relatively constant, indicating heightened sensitivity to environmental changes.

To effectively conduct coastal vulnerability assessments, it is essential to understand shoreline changes, including erosion and accretion. These changes provide valuable insights into the dynamics of shoreline processes, helping us to better evaluate and address coastal challenges (Kumar et al., 2010). In this study, the average coastline changes surrounding the Andaman Islands were estimated using secondary data from the published research conducted by Mondal et al. (2024). The data was used to determine the rate of erosion and accretion in each tehsil.

To estimate surface ocean currents, the **OSCAR (Ocean Surface Current Analysis Real- time)** database was retrieved. This database utilizes ocean surface height, surface vector wind, and ocean surface temperature to directly estimate horizontal velocity, applying quasi-linear and steady inflow thrust equations. The model integrates geostrophic, Ekman, and Stommel shear dynamics, along with a reciprocal term deduced from the face buoyancy grade. The data is handed on a 1/ 3- degree grid with a 5- day resolution and is generated by **Earth Space Research (ESR).).**

We attained wind speed and specific-relative moisture data from **NASA's POWER design portal, employing the MERRA- 2 assimilation model** developed by NASA Goddard's Global Modelling and Assimilation Office. This model utilizes advanced technologies, including newer microwave oven sounders and hyperspectral infrared radiance instruments. For our analysis of ocean face height in the Indian Ocean, we gathered satellite altimetry data from **Jason- 1 and TOPEX/ Poseidon** for the period of 2008 to 2018, sourced from the Radar Altimeter Database System website maintained by the **Department of Earth Observation and Space Systems**. All data were originally imaged using the **NASA Giovanni** web interface, allowing us to download corresponding Net CDF lines for each parameter for comprehensive analysis. also, soil salinity data and ground control points necessary for mangrove mapping were collected during a field visit to the Andaman islets.

2.5.3 Land use and Land cover Mapping

LULC was executed for the years 1993 and 2018 using Landsat 5 TM and guard- 2A data, independently. We established training point polygons for ten distinct land cover classes coral reefs, mangrove timbers, non-mangrove timbers, shrubs, open ocean, free land, mudflats, flaxen strands, and civic areas. False- colour mixes from Landsat 5 and guard- 2A, alongside Google Earth imagery, effectively eased the isolation between colourful land cover classes. The LULC groups for 1993 and 2018 were verified with their separate false- color composites and from Google Earth imageries. By exercising the image interpretation key by SAC (1991), we linked the

LULC features grounded on critical rudiments similar as tone, texture, size, shape, pattern, and association within the satellite images. Variations in land use and land cover were determined through onscreen bracket, clinging to the methodology defined by Prabaharan et al. in 2010. After assessing the temporal changes and verifying the ground truth grounded on Kuldeep and Kamlesh's study n from 2011, we prepared the final charts using ArcGIS 10.5 software. To ensure the utmost appropriateness of mapping we conducted visual confirmation with stratified sample points, exercising Google Earth and applicable literatures from Gupta et al. (2018), and Reddy et al. (2016) to support our findings. These comprehensive measures were enforced to guarantee maximum perfection in the bracket of mangrove cover.

2.5.4 Coral Reef Mapping

In 2018, the classification of reefs in the Andaman Islands was attempted using the SENTINEL-2A series of satellite images. Following the methodology detailed by Anderson et al. (2002), correction of the images was performed using the **Fast Line-of-sight Atmospheric Analysis of Hypercubes (FLAASH**). Subsequently, the **Depth Invariant technique** was employed to adjust for the water column, as outlined by Zoffoli et al. (2014). The Depth Invariant Algorithm, also known as Lyzenga's algorithm, is a straightforward method for correcting water column effects that does not require knowledge of the scene's overall local complexity. The main assumption is that variations in pixel depth on the same substrate account for dissimilarities in radiances at unlike depths and the equation follows: (ln $(L_{TOA,i})$-$(L_{TOA,\infty,i})$) versus (ln $(L_{TOA,j})$-$(L_{TOA,\infty,j})$). Slope of the regression corresponds to a deputation of the lessening coefficient ratio $K_{d,i}/K_{d,j}$. As a result, a new image configuration of corrected radiance in bands i and j (pseudo-colour band) is generated (Lyzenga,1978).

The **FLAASH** model, grounded on the **MODTRAN 4** radiation transfer model, (inbuilt in **ENVI 5.3**) provides a precise way to account for atmospheric influences (Agrawal et al., 2011). This model utilizes look-up tables across five dimensions—optical depth of the atmosphere, wavelength, atmospheric water vapor, topography elevation, and, pixel position —as indicated by Staenz et al. (2002) and Chakouri et al. (2020). FLAASH calculates surface reflectance effectively.

$L(\lambda) = \frac{A\rho}{1-\rho e S} + \frac{B\rho e}{1-\rho e S} + L_{\alpha}(\lambda)$ were,

A and *B* Coefficients that relies on conditions of the atmosphere

ρe: Mean surface reflectivity for a pixel;

La(λ): Radiance backscattered by atmosphere;

S: Spherical albedo of the atmosphere;

ρ: Pixel surface reflectance;

(Chakouri et al.,2020).

In 2018, a comprehensive field study was conducted focusing on coral bed classification through spectral signature analysis. This classification employed a knowledge-based approach, utilizing sampling points and rectified images. In the initial stages, the land portions of the images were obscured to concentrate on the water sections, which were then categorized in 200 classes using Maximum Likelihood classifier technique (MLC). To enhance the quality of the classified raster images, a 3x3 kernel size statistical filter was applied, to effectively reduce data volume prior to vectorization. It's crucial to recognize that while merging optically similar classes can streamline data, it may inadvertently decrease the overall accuracy of the map. To mitigate this risk, diligent background editing was executed on the vector data to correct any inaccuracies that had been introduced during the classification process. Rigorous quality checks ensured the thematic accuracy of the maps prior to the establishment of a digital database. The creation of continuous classified images for each reef region was achieved using Erdas Imagine (version 9.0) and ArcGIS (version 10.5) software. This process also involved meticulous edge corrections to maintain data continuity across the seamless mosaics. Ultimately, an elaborate quality assessment was executed, focusing on both database integrity and thematic accuracy, culminating in the finalization of the digital database that delineates distinct coral eco-morphological zones (Green et al., 2000; Gibson et al., 2007; Nair et al., 2017; SAC,2012). Additionally, the Space Application Centre published a journal titled "Coastal Zones of India" in 2012, which referenced Hopley's (1982) morphological classification of reefs. This classification framework was integral to the current study, with its accuracy verified through consultation of existing literature.

2.5.5 Mangrove mapping and Forest Health Assessment

For the purpose of mangrove mapping, ground control points (GCPs) were predominantly collected from the peripheral patches of mangroves. This strategic approach was adopted to enhance the accuracy of distinguishing mangrove vegetation from surrounding non-mangrove flora. In the Andaman region, the GCP locations were systematically distributed across various sites, including Aerial Bay, Rangat, Kadamtala, Baratang, Shoal Bay, Chouldari, Wandoor, Manjery, Chidiyatapu, and Bambooflat. For vegetation analysis using LANDSAT images, it's crucial to correct for gain bias, scattering effects, and sun angle. In this study, we corrected the Green, Red, and NIR bands of the Landsat TM. The data were calibrated to convert digital numbers (DN) into top of atmosphere (TOA) spectral radiance and then into TOA planetary reflectance. The DN values were converted into TOA reflectance without sun angle correction using the following formula:

$\rho\,\lambda' = M\rho\ Qcal + A\rho,$

where ρ = TOA planetary reflectance, without correction for solar angle.

$M\rho$ =Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_ BAND_x, where x is the band number)

$A\rho$ =Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number)

Qcal = Quantized and calibrated standard product pixel values (DN) Now the Sun Angle correction have been achieved using the following formula

$\rho\,\lambda' = \frac{\rho\,\lambda'}{\cos\theta_{SZ}} = \frac{\rho\,\lambda'}{\sin\theta_{SE}}$ Where: $\rho\,\lambda'$ = TOA planetary reflectance θ_{SE}= Local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION). θ_{SZ}= Local solar zenith angle; $\theta_{SZ} = 90^{\circ} - \theta_{SE}$.

The NDWI index was applied to analyze images, revealing its effectiveness in distinguishing mangrove areas due to their high leaf water content. In contrast, NDVI assesses plant chlorophyll content through leaf greenness and reflectance in the red and NIR bands. To differentiate mangroves from other vegetation, we developed a simple algorithm that subtracts NDWI values from NDVI values at the pixel level. This subtraction, leveraging their negative correlation, enhances the distinction between classes with similar spectral signatures. The resultant Combined Mangrove Recognition Index (CMRI) algorithm was tested in the Andaman Islands, where a robust negative correlation between the two indices was observed (r = 0.987 and r = 0.989). Ground control points were plotted using ArcGIS 10.3 and categorized by vegetation type observed in the field into mangroves and non-mangroves. Vegetation types from the CMRI INDEX were classified, with distinct colors assigned (red for mangroves and green for non-mangroves) (Gupta et al.,2018). The classification accuracy was assessed using Kappa statistics.

Assessment of mangrove health in the Andaman Islands was rigorously conducted using the NOAA AVHRR-based Global Vegetation Index, which cartels the Temperature Condition Index (TCI) and Vegetation Condition Index (VCI) at a 16 km resolution. This methodology follows the established techniques outlined by Ghosh and Mukhopadhyay (2014). The Temperature Condition Index effectively illustrates thermal conditions through brightness temperature, while the Vegetation Condition Index clearly indicates the greenness of the plants (Kogan, 1995).

$$VCI = 100(NDVI - NDVImin)/(NDVImax - NDVImin)$$

$$TCI = 100(BTmax - BT)/(BTmax - BTmin)$$

Finally, the Vegetation Health Index was calculated as:

$$VHI = 0.5 * VCI + (1 - 0.5) * TCI \ .$$

2.5.6 Flood inundation mapping

The framework established by Prerna et al. (2015) was followed for flood inundation risk mapping for biophysical and social vulnerability assessment. To extract the areas that will be flooded along the Andaman Islands' coastline, SRTM data with a resolution of 90 meters was used. Delineating the locations where the ground elevation is lower than the wave height is crucial for accurately determining the inundated areas of Andaman Islands. Utilizing several tools and logical expressions within the ArcGIS environment allows for precise identification of flooded areas. Initially, the raster representation of wave height is converted to a "Point" format. This involves creating a grid of equally sized cells, known as a "fishnet," which interpolates values from both the interior and exterior of each cell to ensure continuous wave height data. Subsequently, the regions of the SRTM area that are equivalent or lesser than the Tsunami heights are extracted using the "Less than Equal" function, effectively pinpointing the affected areas.

The SRTM elevation data were utilized to classify three flood risk zones namely:

- High-risk zones with elevation of 2-4 m
- Medium risk zones of elevation of 4-6 m.
- Low-risk zones having elevation of 6-8 m

It was sufficient to manually classify the elevation values in ArcMap 10.5 software to visualize the regions that fall into the various categories, as shown in (Chap.4 Fig 4.5.4). To quantify the percentage of mangroves and corals found in high-risk flood zones appropriate spatial analytic tool included in the ArcGIS 10.5 suite were utilized.

2.5.7 Min Max Rescaling Transformation

Every vulnerability literature review has clearly identified two dominant approaches for evaluating the vulnerabilities (1) an inductive approach, which relies on relying on statistical relationships, and (2) a deductive approach, rooted in a theoretical understanding of the above relationships (Yoon, 2012; Cutter et al., 2003).

When utilizing the deductive approach, researchers often amalgamate selected variables into a composite value, employing normalization or standardization techniques (Yoon, 2012). This standardization process is essential since vulnerability index variables are frequently measured in various units. To eliminate differences in measurement units, methods such as min-max rescaling, maximum value transformation, and z-score normalization are routinely utilized.

Min-max rescaling, in particular, effectively transforms each variable to a consistent range between zero and one—where zero signifies the lowest rank for a given indicator and one indicates the highest. This technique scales all other values from the minimum to the maximum, exemplified by the equation:

$$M_i^{index} = \frac{M_{max} - M_i}{M_{max} - M_{min}}$$

were,

M_{min} is the minimum and M_{max} is the maximum values, for each component and M_i is the value of the major component *i*.

2.5.8 Mangrove and Coral Vulnerability Assessment using IPCC AR4 framework

The methodological frameworks of vulnerability for this study are anchored in the IPCC AR4 working definitions. According to these definitions, vulnerability is determined by

$$VI = (E - AC) * S$$

were,

S= Sensitivity, E= Exposure, AC= Adaptive Capacity and VI= Vulnerability Index

Additionally, the factors have been evaluated across different scales, and to ensure consistency, they have been normalized for all variables. These elements were then integrated using a specific equation.

The final products were displayed as a vulnerability index map within a particular GIS environment, with the tehsils arranged from highest to lowest in terms of the vulnerability ranking of mangroves and corals.

2.6 Integrated Social Vulnerability (SVI) Assessment of Population of Andaman Island

An integrated vulnerability framework was applied to measure the vulnerability of communities of the Andaman Islands in social context. This method evaluates the extent of the susceptibility of communities to risks of climate change risks as well as their capacity to cope with such risks by taking into account social dynamics, institutional characteristics, and the economic and political circumstances of individuals (Fussel & Klein, 2006). The framework emphasizes that social factors significantly influence the mitigation or intensification of climate change impacts. These factors can alter the system's sensitivity, which includes individuals, organizations, communities, and various sectors (Brooks, 2003; Houghton, 2009). To measure sensitivity of the island dwellers, coastal erosion data were integrated with socioeconomic indicators, alongside biophysical parameters such as temperature, rainfall, and sunlight. This study evaluated the social vulnerability of the Andaman population in relation to climate change impacts using the IPCC's AR4 framework (Fig 2.6).

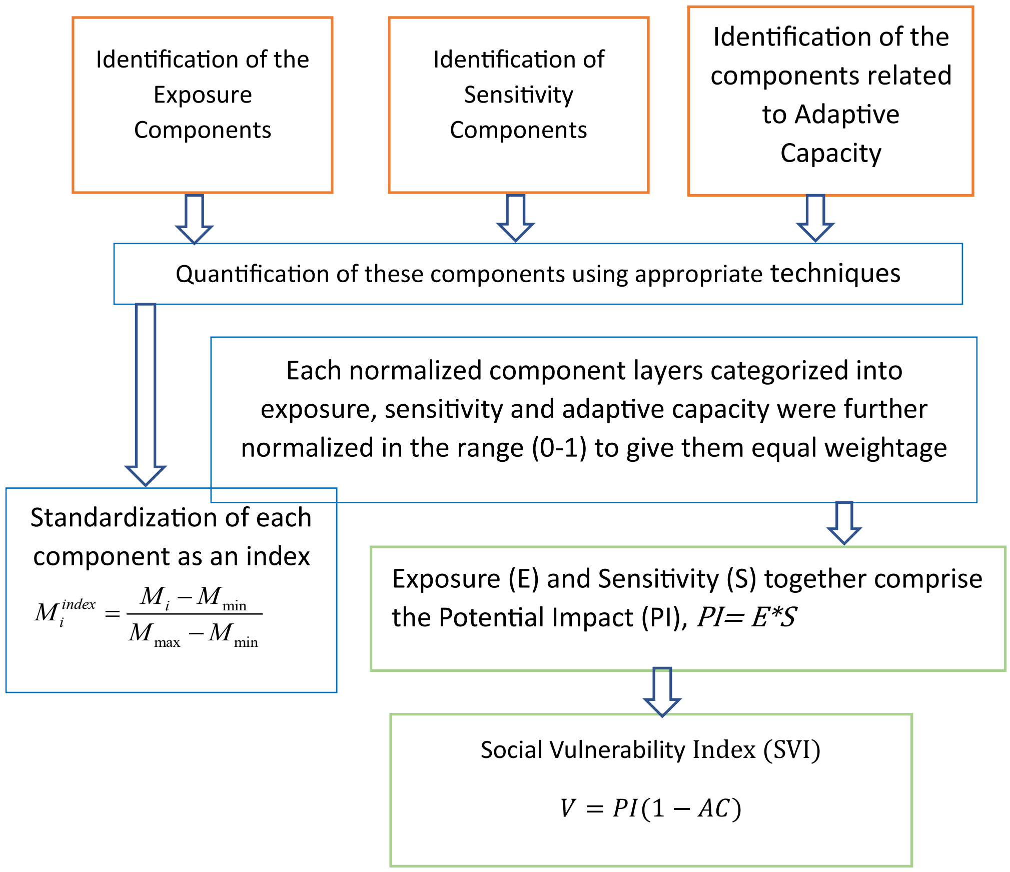


Fig 2.6 Methodological framework of Integrated Social Vulnerability Assessment

2.6.1 Selection of variables.

Twenty-four theoretically significant and pertinent physical and socioeconomic variables were chosen under nine major components (concepts) based on a thorough analysis of literatures and secondary data sets that were made available (Table 2.6.1). By AR4 criteria, climate variability and natural hazard components were categorized into an exposure category.; demographic profile, socioeconomic level, and livelihood activity was classified under the sensitivity factor. Human resource capacity, economic security, infrastructure, and basic amenities were grouped under the adaptive capacity component Low-income groups, the rural population, the uneducated and female population, the elderly and young, and the differently abled are frequently regarded as those most exposed to the threats of climate change under the socioeconomic resource category. Compared to men, women have greater obstacles in overcoming or facing disasters due to their work in specialized sectors, household responsibilities, and child rearing (Cutter et al. 2003). Rural and tribal populations are less equipped to handle disasters because they are low-income and heavily dependent on natural resources. In a similar vein, those who make their living through agriculture are also affected by natural hazards and climate variability (Cutter et al. 2003). Literate individuals engaged in service sectors or as entrepreneurs possess a significant advantage in terms of accessing early-warning information. This enables them to prepare effectively for responding to climate stress or extreme events. In contrast, marginalized workers and poverty illustrate the challenges posed by restricted access to resources and income opportunities. These disparities highlight the need for targeted interventions to support vulnerable populations.

The system's capacity to respond and recover from the effects of extreme events is determined by factors including road density, health care facilities, and educational institutions, as well as access to electricity, safe drinking water, sanitation, etc. (Cannon et al., 2003).

Table 2.6.1 Social Vulnerability components and their measuring techniques

IPCC Contributing Factors	Concepts	Variables	Explanation of Variables	Reference
Exposure	Climate variability	Temperature	IMD time series temperature data.	Field (1995), Alongi (2008)
		Precipitation	TRMM rainfall data	Kumar et al.,2017
	Natural hazards	Flood	Percentage of area inundated during incidence of Tsunami using DEM	Prerna et al.,2015
		Cyclone	Wind speed data	https://power.larc.nasa.gov
		Coastal erosion	Rate of coastal erosion in sq. km/ year	Balica et al.,2012; Das et al.,2020
Sensitivity	Demographic profile	Population density	Number of People / sq.km	Armas and Garvis,2013
		Average household size	Average number of people per household	Adger,1999
		Female population	Percentage of females to total population	Nguyen,2015
		Child Population	Percentage of children under 7 years of age to total population	Nguyen,2015
	Socio-economic status	Rural population	Percentage of rural to total population	Cutter et al.,2003
	Livelihood activity	Agricultural dependents	Percentage of cultivators to total working population	Heltberg et al.,2011
		Marginal workers	Percentage of marginal workers to total working population	Kapur,2010
		Non- workers	Percentage of non- workers to total working population	Myers et al.,2008
	Human resource	Literacy rate	Percentage of literates to the total population age 7 years and above	McCarthy et al.,2001
	Economic security	Home ownership	Percentage of households who do not have their own house	Cutter et al.,2003
		Household assets	Percentage of households who do not have their own assets	Vincent,2004
Adaptive Capacity	Infrastructure	Kuccha house	Percentage of households living in Kuccha house	Das et al.,2020
		Health care centres	Number of medical facilities	Yoo et al.,2011
		Educational institutes	Number of educational institutions	Bryant et al.,2000
		Transport and communication	Number of vehicles	
		Approach by pucca road	Road length in per sq. kms.	Brooks et al.,2005
	Basic facilities	Sanitation	Percentage of households having no sanitation facility within premises	Das et al.,2021
		Electricity	Percentage of households having no electricity connection	Das et al.,2021
		Safe drinking water	Percentage of households where pond, spring, river are the main source of drinking water	Das et al.,2021

2.6.2 Data Acquisition

The Census of India (2001 & 2011) provided all socioeconomic data sets about the components of Adaptive Capacity and Sensitivity. Demographic data of tehsils of Andaman were also obtained from the Basic Statistics 2011–2022, Directorate of Economics and Statistics, A&NI Administration and District Census Handbook, 2021. The monthly temperature records for the period 1990–2018 were logged from IMD (Indian Meteorological Department) time series data for exposure-related factors. For mapping flood risk zones, the regional elevation and coastal slope were extracted as explained in section 2.6.6). The published research on the average coastline changes surrounding the Andaman Islands by Mondal et al (2024) was referred to as secondary data. **Landsat 5 TM** and **Sentinel-1** satellite products were acquired for mapping erosion and accretion. Monthly averaged precipitation time series (January 1998–December 2018) data were aquired from TRMM platform. The **NASA POWER** project portal **(**https://power.larc.nasa.gov/) was used to gather wind speed data.

2.6.3 Deductive Approach Min Max Standardization

We employed min–max rescaling methods to effectively convert twenty-four carefully selected variables, following Yoon's (2012) integrated SVI approach.

$$M_i^{index} = \frac{M_{max} - M_i}{M_{max} - M_{min}}$$

The details of the technique have been already explained in the previous section 2.5.7

2.7 Assessing Future Coral Bleaching Events and Strengthening the Sustainability of Coastal Fisheries in the Andaman Islands in Response to Climate Change

The potential effects of climate modification on corals in the form of probable bleaching events, their frequency and intensity, and corresponding stress on the fisheries were assessed with the aid of the bias-corrected CNRM-CM5 earth system model run of the RCP 4.5 scenario and probable occurance of bleaching incidences estimated from Degree Heating Weeks. The methodological framework is illustrated in Fig 2.7. Using the CMIP5 model under appropriate RCP 4.5 scenario, the potential model predictions were examined for 2030, 2050, and 2080 for SSTs of the Northern part of BoB Sea (Majumdar et al., 2022)

2.7.1 Data set used

- **Observational Data set-** Ocean surface temperature data for the period 1982–2019 from **GHRSST Level 4 AVHRR_OI Global Blended Sea Surface Temperature Analysis (GDS version 2) data from National Centres for Environmental Information** (NCEI 2016; Reynolds et al. 2007) were used for the present study for model callibration, along with **MODIS Terra Level 3 SST 872 thermal IR daily 4 km night time V2019.0 data** from 2000–2019 (Werdell et al. 2013; NASA OBPG 2020) retrieved from (http://podaac.jpl.nasa.gov) for model validation..

- **Model data set-** Observation data were combined with the daily forecast SST data for the years 2006 to 2099 from two climate models under the CMIP5 project.
  1. **HadGEM2-ES** (ensemble = r1i1p1; experiment = Historical, RCP 4.5 and RCP 8.5), and
  2. **CNRM-CM5** (ensemble = r1i1p1; experiment = Historical, RCP 4.5 and RCP 8.5) accessed from Earth System Grid Federation (ESGF) **UK Met Office Hadley Centre HadGEM2-ES** (ensemble = r1i1p1; experiment = Historical, RCP 4.5 and RCP 8.5), and
  3. **Centre National de Recherches Meteorologiques/Centre Europeen de Recherche et Formation Avanceesen Calcul Scientifique (CNRM/CERFACS) CNRM-CM5** (ensemble = r1i1p1; experiment = Historical, RCP 4.5 and RCP 8.5) accessed from Earth System Grid Federation (ESGF) node esgf-data1.ceda.ac.uk and esgf-node.ipsl.upmc.fr

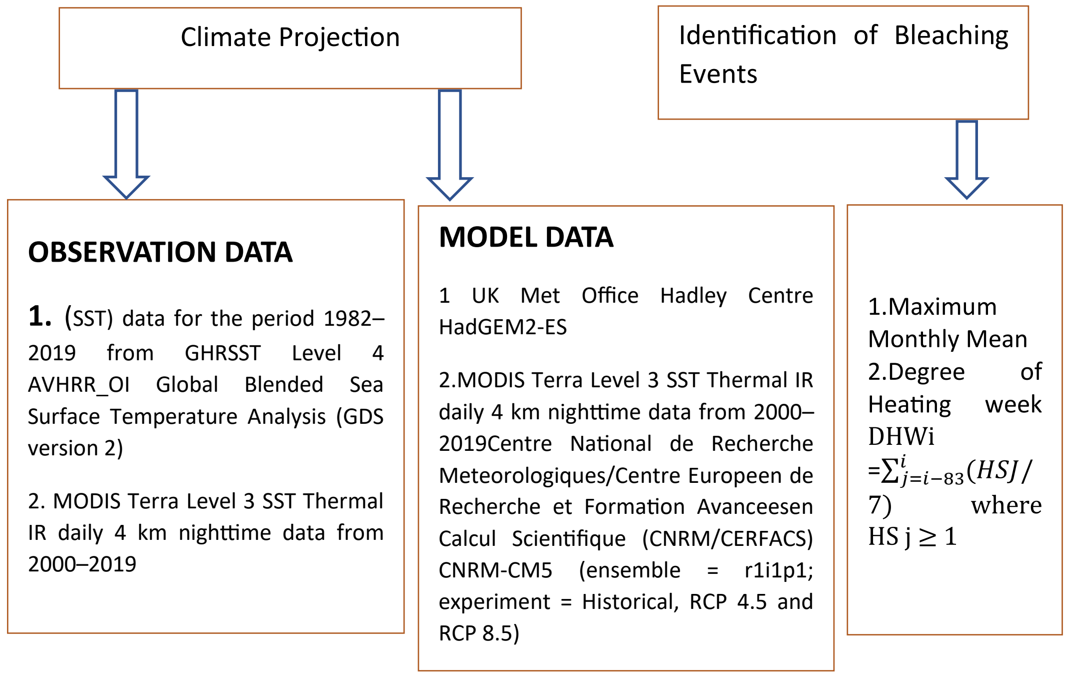


Fig 2.7 Methodological Framework for assessing Future Bleaching Events

2.7.2 Identification of bleaching events

Two distinct methods were utilized to accurately identify coral bleaching events resulting from heat stress. Coral reefs experience bleaching when the sea surface temperature (SST) surpasses a certain threshold, specifically when it rises one degree Celsius (1°C) above the maximum monthly mean (MMM), which reflects the highest summertime mean temperature. To effectively detect these events, a straightforward threshold technique was employed (Glynn and D'Croz 1990). In addition, a more sophisticated method DWH was implemented that assesses the collective thermal stress experienced in a region over the previous 12 weeks, thereby providing a comprehensive means of identifying bleaching occurrences (Majumdar et al., 2022).

2.7.3 Maximum Monthly Mean

Maximum Monthly Mean (MMM). is considered as the warmest monthly mean value. To compute monthly mean composites, daily GHRSST-AVHRR observation SST data from 1982 to 2005 were used.

2.7.4 Hot Spots

The occurrence of thermal stress that is getting close to being favourable for coral bleaching at a place is measured as a coral bleaching hot spot (HS) (Liu et al., 2003, 2005). The mean Sea Surface Temperature (SST) prevailing in the hottest month serves as the foundation for the HS anomaly (Skirving et al., 2006). Areas where the SST is higher than the Maximun Monthly Mean of SST are referred to as hot spots. The discrepancy between the MMM SST climatology and the measured near-real-time SST is indicated by the value of HS, which is computed as

$$\text{Hot Spot (˚C)} = \text{SST} - \text{MMM}$$

Since the hot spot indicates bleaching heat stress over MMM climatology, only positive values are taken into account (Majumdar et al., 2022).

2.7.5 Degree of Heating week

The degree of heating week (DHW) is a crucial metric for quantifying the heat stress experienced by coral reefs, particularly over a period of twelve weeks. It accumulates instances where water temperatures exceed 1°C, thereby highlighting potential coral bleaching hot spots. This measurement not only considers how long the corals have been exposed to elevated temperatures but also the intensity of that heat. Research has shown that DHW values exceeding 4 °C-weeks lead to significant bleaching of corals, while values surpassing 8 °C-weeks can cause severe bleaching and substantial mortality in coral populations. Understanding and monitoring DHW is essential for protecting coral reef ecosystems. The formula used to calculate the DHW is given below.

$$DHW_i = \sum_{j=i-83}^{i} \left(\frac{HSj}{7}\right)$$

where HS j ≥1 °C

The formula effectively calculates the Daily Heat Water (DHW) value for a specific day (i), represented as DHWi. It considers the accumulated heat stress from coral bleaching hot spots (HSj) that reach 1 °C or higher over a rolling 12-week period (84 days) leading up to that day. Given that coral bleaching generally evolves over a week, the DHW is quantified in °C-weeks, applying a division factor of 1/7 (ibid). A particular location can have a positive DHW value on a given day even if the HS value is at or below 0 °C. This simply signifies that heat stress was recorded at that site within the preceding three months, suggesting that while local conditions may not currently be stressing the corals, prior exposure could still have detrimental impacts (Majumdar et al., 2022

2.8 Scope of Sustainability of Tourism in Andaman Island

A thorough evaluation of the island's capacity for sustainable development was conducted for addressing significant challenges posed by excess tourism. This research was systematically divided into three key stages: (1) analyzing the phases of tourism development in the Andaman Islands from 1981 to 2021, utilizing Tourism Area Life Cycle model; (2) employing trend function exploration techniques to forecast the destination's trajectory from 2011 to 2051; and (3) assessing the risk of over-tourism at the island's most frequented beaches by examining Tourism Carrying Capacity through metrics such as the Tourist Operation Index, Tourist Density Index, and Beach Impact Index (Vandarakis et al., 2018; Kyrıakou et al., 2017) Fig 2.8.

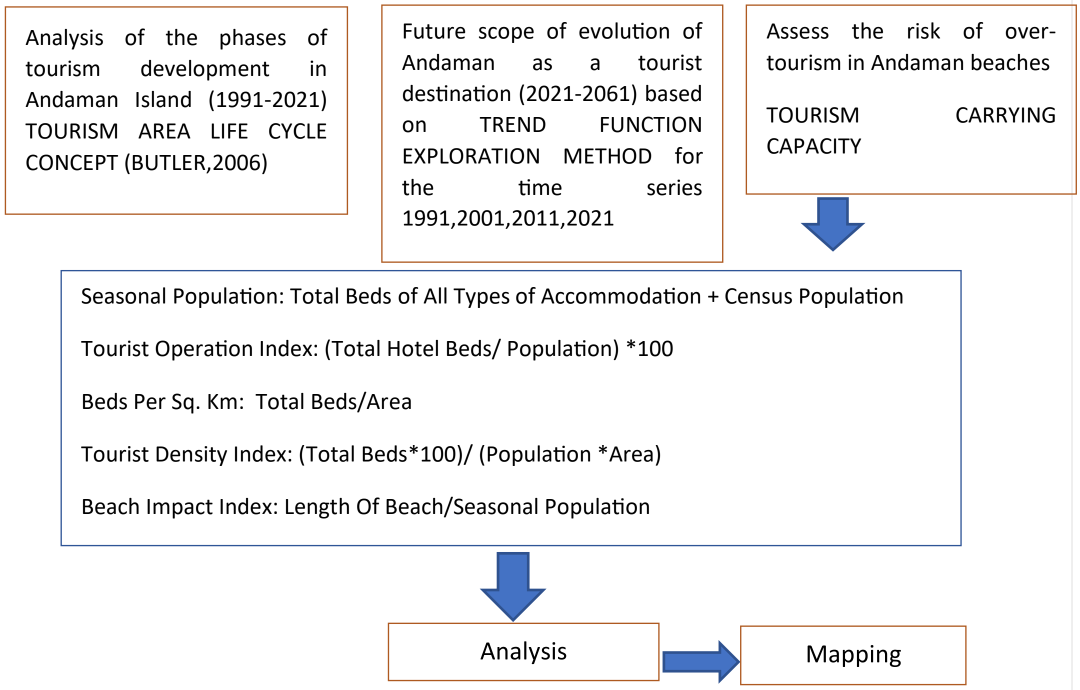


Fig 2.8 A layout of methodology to assess over- tourism in Andaman Island

2.8.1 Data set used

1. All the data encompassing tourism sectors of Andaman Islands were acquired from **Tourism Statistics of Andaman and Nicobar Island 2016**, **The Department of Information, Publicity and Tourism (IP&T), A&NI Administration**; and **Directorate Tourism Andaman and Nicobar Administration**

2. Data on monthly tourist arrival (domestic and foreign) in A&NI between 1980–2006 were obtained from **Tourism Statistics of Andaman and Nicobar Island 2021** and Directorate Tourism Andaman and Nicobar Administration (https://www.andamantourism.gov.in).

2.8.2 Tourism Area Life Cycle Model (TALC)

Tourism Area Life Cycle model systematically outlines stages of a destination's development, guided by visitor numbers and infrastructure growth. This model comprises six definitive stages:

- The exploration stage initiates tourism at a destination, drawing visitors to its pristine natural and cultural attractions, without significant impact on the environment (Uysal et al., 2012).
- During the involvement stage, visitor numbers stabilize, leading locals to establish basic hospitality services. Enhanced transportation options emerge, and the local lifestyle transitions as the government becomes actively involved in fostering development (Butler, 1980; Gore et al., 2021).
- In the development stage, tourism expands significantly. The creation of a distinct tourist market occurs alongside extensive advertising campaigns to draw in tourists. Both national and local governments engage in planning and enhancing attractions, making this stage pivotal for quality management. Once the consolidation stage is reached, tourism evolves into a fully established industry.
- The stagnation stage sees a shift toward psycho-centric tourists and a reliance on repeat visitors, highlighting the destination's carrying capacity. This leads to ecological, environmental, and social issues as tourism organizations grapple with declining occupancy and reduced marketing efforts, causing the destination's allure to fade (Butler, 1980; Gore et al., 2021).
- Subsequently, the decline stage manifests through decreased tourist arrivals and a drop-in market activity. While day-trippers may still visit, the overall tourism sector suffers, resulting in infrastructure decay and conversion of hotel spaces into retirement homes. Traffic management issues and environmental degradation ensue, ultimately threatening the cultural essence of the region (Uysal et al., 2012).

The study conducted, initially involved analysing data and identifying phases of tourism development in Andaman using Butler's TALC paradigm from 1980. The model for Andaman was constructed based on tourist arrival data, employing simple exponential smoothing to clarify the underlying trends of the time series by minimizing anomalies (Brown, 1959). Annual growth rates of the smoothed data were computed and standard deviations of these rates were determined for local, foreign, and total tourists, revealing 0.102, 0.145, and 0.101 respectively. Graphs representing local, foreign, and total tourist data were referenced to compare variances and analyze trends across each stage (Gore et al., 2021).

2.8.3 Trend Function Exploration Method

In the second step of the research (Fig), an analytical model was used to calculate the Andaman's evolution phase of tourism from 2011 to 2051. The Trend Function Exploration method makes it easier to anticipate tourist traffic flow when there are trends toward development and unintentional swings in the time series (Majewski, J;2013). The R-squared values were computed for the total tourists, number of hotels, and resident figures for the years 1991, 2001, and 2011. Out of linear, logarithmic, power, exponential, or polynomial models the best fitted one was selected (Widz and Wojcik, 2020). The forecast of the development of tourist destination was derived from a trend line.

2.8.4 Tourist Carrying Capacity

The idea of TCC dates back to the 1960s (Coccossis and Mexa, 2004; Pstrocka, 2004). WTO defines tourism carrying capacity as "the maximum number of tourists that can visit a destination without harming the immediate environment (UNWTO, 2004). This definition has established a framework for creating an indicator (Manera and Valle, 2018) that facilitates the identification of threshold values, which are crucial for sustainability and the conservation of the natural environment (Witz and Wojcik, 2020).

Buttler (1980) delineated the stages of a tourist destination's development, emphasizing the necessity of planning and managing tourism resources wisely. O'Reilly (1986) highlighted that TCC should factor in the maximum growth rate to prevent detrimental effects on destinations. Martin and Uysal (1990) examined how carrying capacity relates to the tourism lifecycle, advocating for informed policy-making. Accurate quantification of carrying capacity with well-chosen indicators aids in evaluating both the potential benefits and drawbacks for tourist destinations, which must be analyzed through physical, social, and economic lenses (Vandarakis et al., 2023).

In the third step of the present study, all the major beach tourist destinations in Andaman were chosen to explore tourism carrying capacity indicators. The indices were selected depending on data availability for each tehsil (Table 2).

- Seasonal Population - The population of a location tends to reach its highest point at specific times of the year, influenced by various attractions for non-resident visitors. For example, tourist activity often peaks in sea beaches during summer and mountainous regions during the winter (Roman and Stokes, 2015). To gauge the temporary population, occupancy rates of tourist accommodation establishments are frequently utilized. However, these figures can be skewed by the shadow economy, which includes illegal establishments, as well as tax evasion by legitimate operations that do not fully report all bookings (Lagos & Diakomichalis,2014).

  The Seasonal Population Density Index (SPI) was calculated as

  $TOTAL\ BEDS\ OF\ ALL\ TYPES\ OF\ ACCOMMODATION + CENSUS\ POPULATION$ (Lagos & Diakomichalis,2014)

- The Tourist Operation Index (TOI) measures the proportion of total hotel beds at tourist facilities compared to the overall census population of the region. The TOI value is always represented as a percentage.

$$\frac{TOTAL\ HOTEL\ BEDS}{POPULATION)} * 100$$

- The Tourism Density Index (TDI) was calculated from the equation (Lagos & Diakomichalis, 2014)

$$\frac{TOTAL\ BEDS * 100}{POPULATION\ * AREA}$$

- For calculation of the Beach Impact Index, popular beaches of each tehsil were selected as detailed in Table. The beach lengths were visually digitized in Google Earth Engine and their length were determined. Finally, the Beach Impact Index or BII was calculated from the equation (Vandarakis et al., 2018)

$$\frac{\text{SEASONAL POPULATION}}{\text{BEACH LENGTH}}$$

The final outputs were presented in a TCC map in a specific GIS environment, where the vulnerable tourist spots of the island and the candidate areas for possible sustainable tourism development were depicted.

2.9 Ethical Considerations

The research team and partner organizations connected to this project have made intentional efforts to uphold the ethical integrity of both the research process and its results. The following guiding principles have been observed:

- Safeguarding the confidentiality of information and ensuring the anonymity of individuals upon request.

- Upholding the integrity of the data to prevent falsification, plagiarism, or fabrication of results.

- The study was conducted with full awareness and obtained requisite permissions from village heads or local elected representatives where applicable.

2.10 Research Limitations

- The survey conducted in the Andamans between 2017 and 2020 was limited to just two instances, primarily due to the constraints of time-sensitive research and available resources. The onset of the COVID-19 pandemic has further restricted access to the islands, which has critically impacted any efforts to survey community social vulnerability or assess tourism.
- Efforts to collect primary data from hoteliers of the islands through a questionnaire survey approach were largely unsuccessful. Additionally, attempts to conduct interviews with key senior officials from the A&NI Administration were thwarted by their demanding travel schedules and lack of availability for appointments.
- Consequently, the analysis is constrained by lack of reliable and current secondary data across various crucial indicators. This deficiency includes essential information on tehsil-wise coral species coverage, fishing villages, tehsil-wise fish catch statistics, the total number of accommodation units in the tehsils, and employment figures related to tourism activities. Unfortunately, there are no official records available to substantiate this information.

Regrettably, reliable and up-to-date secondary data concerning various parameters of the island's physical tourist carrying capacity were not accessible. As a result, the study concentrated on establishing a beach carrying capacity index using the available information.

CHAPTER-3

INTRODUCING ANDAMAN ISLANDS

3.1 Introduction

The Andaman & Nicobar Isles known for their stunning sunsets, lush green landmasses set against the deep blue sea, serene aquamarine beaches with pristine white sand, and rich heritage, have drawn tourists for many years. The islands have a strategic geopolitical advantage, providing easy access to countries like Myanmar, Indonesia, Thailand, and Vietnam. They also serve as a gateway to the Indian subcontinent, Southeast Asia, and Myanmar, along with a land route to China. Additionally, their closeness to the Strait of Malacca, one of the busiest global trade routes, enhances their significance, with over 65,000 vessels navigating it each year (Tripathi, 2018). Despite their remote and isolated setting, the Andaman and Nicobar Islands face several vulnerabilities. While a traditional military threat seems unlikely due to India's positive relations with neighbouring Southeast and East Asian countries, poaching, illicit migration, weapon trading, and natural catastrophes pose grave challenges to islands' safety (Das, 2011).

3.2 Locational extent of Andaman and Nicobar Islands

Spanning a land area of 8,249 sq. km, this archipelago is firmly positioned about 1200 km from the Indian mainland and comprises of 572 islands, out of which 38 are populated (Ramesh and Vel.,2011; Dam Roy et al., 2009). These islands lie in the Bay of Bengal, stretching between 6˚45' and 13˚41' N latitudes and 92˚12' and 93˚57' E longitude (Bandopadhyay et al., 2017). The Nicobar Islands, located in the southern part of the Ten Degree Channel extend over 259 square kilometres with maximum width of 58 kilometres. This group encompasses 22 islands, of which 13 are inhabited (Bandopadhyay et al., 2017). The present research is focussed only on Andaman Islands whose spatial extent is 12˚30' N to 92 ˚45' E .

3.3 Geographical Profile of Andaman and Nicobar Islands

The ANI located along a submerged mountainous ridge, stretches from the Arakan Yoma range (Burma) in the north to Sumatra in the south. It is distinctly bordered by Andaman Sea in the east and the Bay of Bengal in the west. A notable physical divider, the Ten Degree Channel (10˚N latitude) measuring 160 km in width separates the Andaman from the Nicobar islets in north- south (Tripathi, 2018).

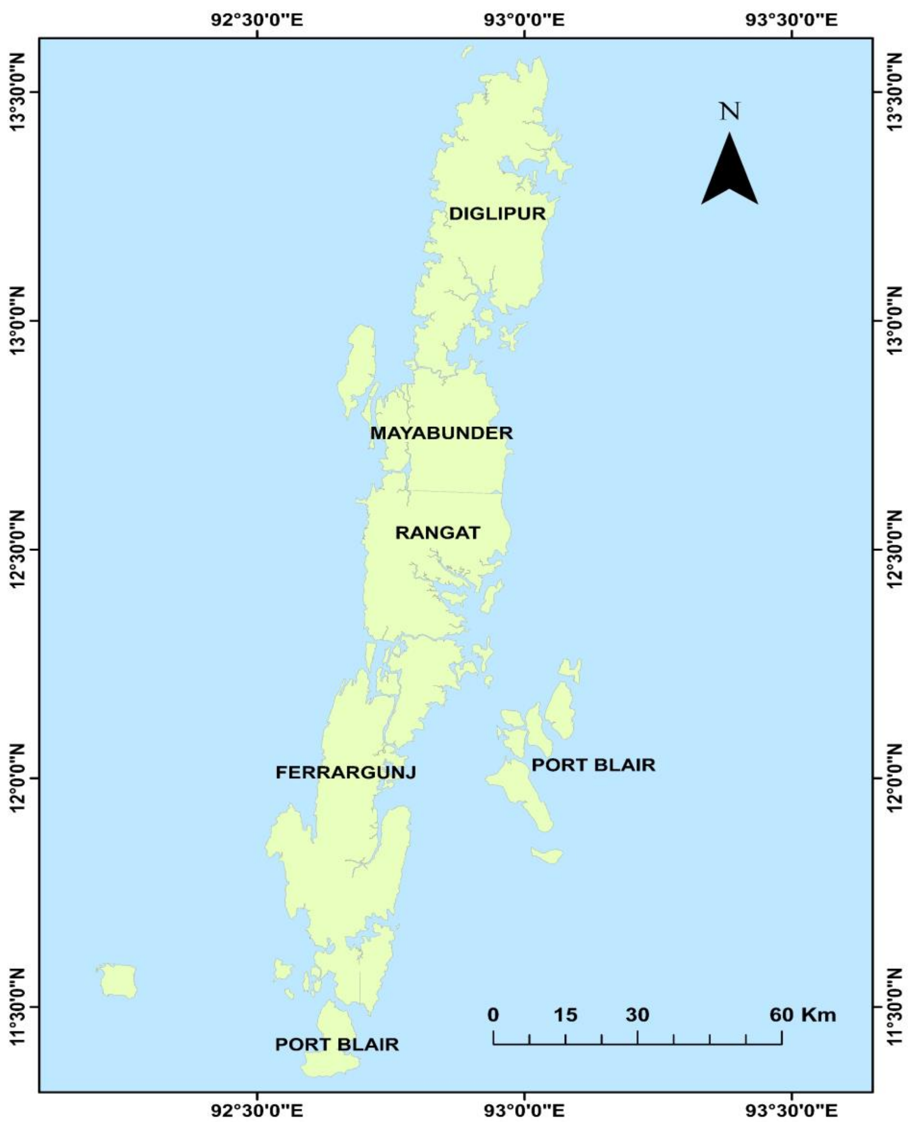


Fig 3.1 The Study Area

The Andaman Group consists of five islands namely- North, Middle, and South Andaman Islands, Baratang, and Rutland. Additionally, Ritchie's Archipelago includes a group of small islands such as Swaraj Dweep, Shahid Dweep and Henry Lawrence Islands (Bandopadhyay et al., 2017). The Little Andaman Island is separated from the Great Andaman by the Duncan Passage. Significant tidal channels, running east to west, separate the large isles. Middle and North Andaman are separated by Austin

Strait, Middle Andaman and Baratang divided by Humphrey Strait, Middle Strait dividing Baratang and South Andaman, and Macpherson Strait between South Andaman and Rutland (Bandopadhyay et al., 2017). Two islands of volcanic origin, Barren and Narcondam Islands, are located in the Andaman Sea (Ramesh and Vel,2011).

One prominent feature of Nicobar Islands is the Nicobar Fan, a part of the Bengal Fan, topographically isolated and stationed to the western side of Nicobar Group (Bowles et al. 1978). The administrative headquarters for this region is on Car Nicobar Island. Significant islands within this archipelago include the largest, Great Nicobar, Little Nicobar, Katchal, Tillangchong, Chowra, Camorta, Nancowry, which spans an area of 1,045 square kilometres. Notably, Indira Point, named after Prime Minister Smt Indira Gandhi, marks the southernmost tip of the country located 147 kilometers from the northern tip of Sumatra (Bandopadhyay et al., 2017).

The Andaman-Nicobar Group features its highest point at Saddle Peak, which stands at 733 meters on North Andaman. Additionally, the volcanic island of Narcondam has the second-highest elevation at 713 meters. Both Great and Little Nicobar boast hilly terrains, with Mount Thullier on Great Nicobar reaching 642 meters (Bandopadhyay et al., 2017).

3.4 Geological profile of Andaman and Nicobar Islands

These Islands represent a vital geological area that holds significant records of major events in South Asia dating back to the Late Cretaceous period. (Ray and Radhakrishna, 2020). Arranged in a north-south orientation, these islands are a key extension of Java-Sunda-Burma subduction composite, located between the Indo-Burma convergent plate boundary (Srijayanthi et al., 2012). The Andaman arc features several remarkable tectonic characteristics, including a transition between convergence and transgression, a significant accretionary prism, and a relatively minor volcanic arc. The accretionary prism is predominantly marked by subaerial islands and contains, trench-forearc sediments, thrusted ophiolites, clastic deposits, tectonic landforms mud volcanoes, and deposits of Tsunami (Srijayanthi et al., 2012). The area includes two notable subaerial volcanoes and likely numerous submarine eruptive centers (Ray and Radhakrishna, 2020).

3.5 Climate Profile of Andaman and Nicobar Islands

The archipelago showcases a tropical to subtropical climate, which remains relatively consistent throughout the year with minimal fluctuations in temperature. The islands enjoy an average relative humidity of 79%, coupled with an average maximum temperature of 30.20°C and a minimum of 23.0°C. Notably, long-term temperature patterns have shown stability, as highlighted by research (Bandopadhyay et al., 2017). These islands receive a substantial annual rainfall of approximately 3100 mm, with Andaman experiencing more precipitation than Nicobar. A significant portion—around 95%—of the rainfall occurs between May and December, leading to a marked dry period from January to April, during which there is typically a shortfall of about 610 mm. Statistically, Port Blair leads with the highest annual rainfall of 3100 mm, whereas Nancowry records the lowest at 2480 mm (Velmurugan et al., 2018; Bandopadhyay et al., 2017).

Rainfall patterns vary seasonally, with the monsoon season contributing the most precipitation, while winter experiences the least. Over the year, the islands generally see about 136 rainy days. Specifically, Andaman Islands average 173 cm of rainfall during the monsoon over 73 rainy days, while Nicobar Islands receive about 113 cm across 56 days. In the winter months, Andaman has a mere 6 cm of rainfall over 3 days, while Nicobar's total is relatively higher at 17 cm with 9 rainy days (Velmurugan et al., 2018). Cyclones tend to form during the southwest monsoon, especially in May, but the northeast monsoon can also bring potent storms. The months of December and January are usually calmer, with February presenting the most favourable weather conditions. Despite their location within a storm-prone region, the islands have been relatively resilient to severe impacts, with only a few significant storms recorded in the past (EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008).

Fig 3.5 a, b and c. represents mean maximum temperature recorded at Port Blair over the period 2001-2023, average annual rainfall received by the Islands (2008-2023) and percentage of humidity recorded in Port Blair respectively (Basic Statistics,2001-2023, Directorate of Economics and Statistics, Andaman and Nicobar Islands).

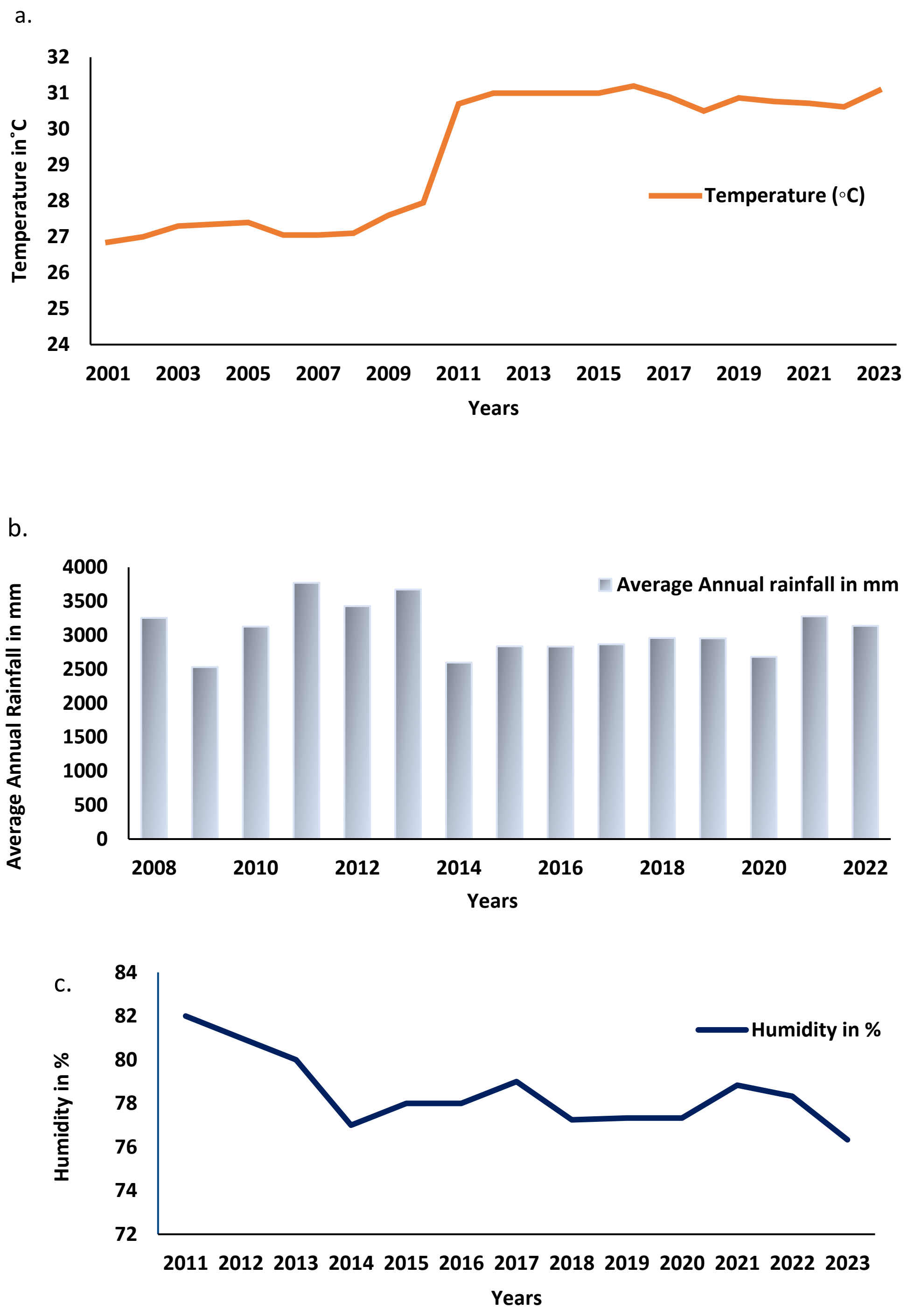


Fig 3.5 The climate profile of Andaman and Nicobar Islands depicting a. mean maximum temperature in ˚C (2001-2023), b. average annual rainfall in mm (2008-2023), c. percentage of Humidity recorded in Port Blair

3.6 Environmental Profile of Andaman and Nicobar Islands

The Islands boast an exceptionally diverse array of terrestrial and marine ecosystems. The forests of Andaman group of islands have been recognized in the Global 200 List of World-Wide Fund as a key biodiversity hotspot, underscoring their significance for conservation initiatives (A&N Islands Action Plan on Climate Change, 2013). A recent evaluation revealed that the islands host a rich variety of plant life, comprising 3,219 species from groups such as angiosperms, gymnosperms, pteridophytes, bryophytes, lichens, and algae, spanning across 1,251 genera (Jaisankar et al., 2018).

a. **FOREST COVER-**. Total forest cover in the Union Territory is 6,742.78 square kilometers, representing 81.74% of its total geographical area. The forest canopy density in the area is categorized into three classes: Very Dense Forest (VDF), with 5,677.52 square kilometers area, Moderately Dense Forest (MDF) covering 683.89 square kilometers, and Open Forest (OF) with 381.37 square kilometers (India State Forest Report,2019). The forest cover has increased by 0.78 square kilometers from 2017 to 2019.
b. **FISHERIES-** The fisheries boast a remarkable diversity, with over 1,150 species of fish across 507 genera and 151 families. These fish inhabit various environments, including freshwater, brackish waters, coastal regions, and the open sea. Key groups of interest include pelagic and deep-sea sharks, skates, stingrays, herrings, moray eels, sardines, milkfish, and various other species (Environmental Impact Assessment Report,2018). The mangrove creeks and backwaters serve as critical nurseries for many fish species during their juvenile stages (Environmental Impact Assessment Report,2018).
c. **MANGROVES-** The mangrove ecosystems in these islands are classified as insular types, benefiting from numerous tidal estuaries, small rivers, and nearby islets, creating an ideal habitat for mangrove forests to flourish (Kathiresan, 2010) (see Fig 3.6 d). With a relative density of 76.5% the dominant true mangrove families include Rhizophoraceae, Acanthaceae, Pteridaceae,etc (George et al., 2018; Mandal and Naskar 2008; Bharati et al., 2014). In total, around 35 true mangrove species are identified, spanning 13 families and 19 genera throughout the islands. (Ragavan et al., 2018).

Table 3.6b. Marine Fish species and their production in tonnes (Source:Environmental Impact Assessment Report,2018).

Years

1997
1998
1999
2000
2001
2003
2004
2006
2007
2008
2009
2011
2012
2013
2014
2015

Years	Elasmobranchs	Silver bellies	Perches	Pomfrets	Carangids	Half and Full Beaks	Barracuda	Neritic Tuna	Pelagic Sharks
1997	886	1405	1926	345	1350	390	842	0	0
199	1157	1090	1482	472	1139	113	1022	0	0

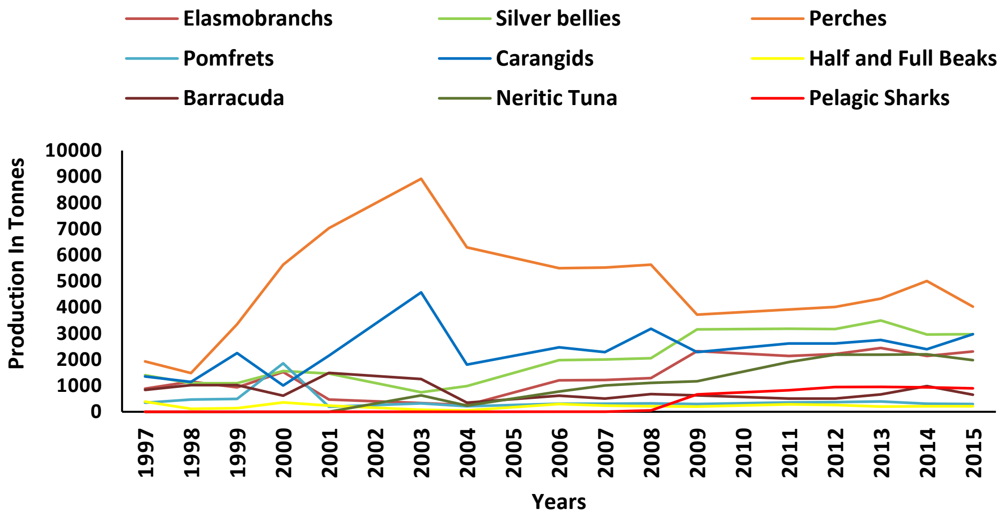


Fig 3.6b. Marine fish species and their production in tonnes (1997-2015)

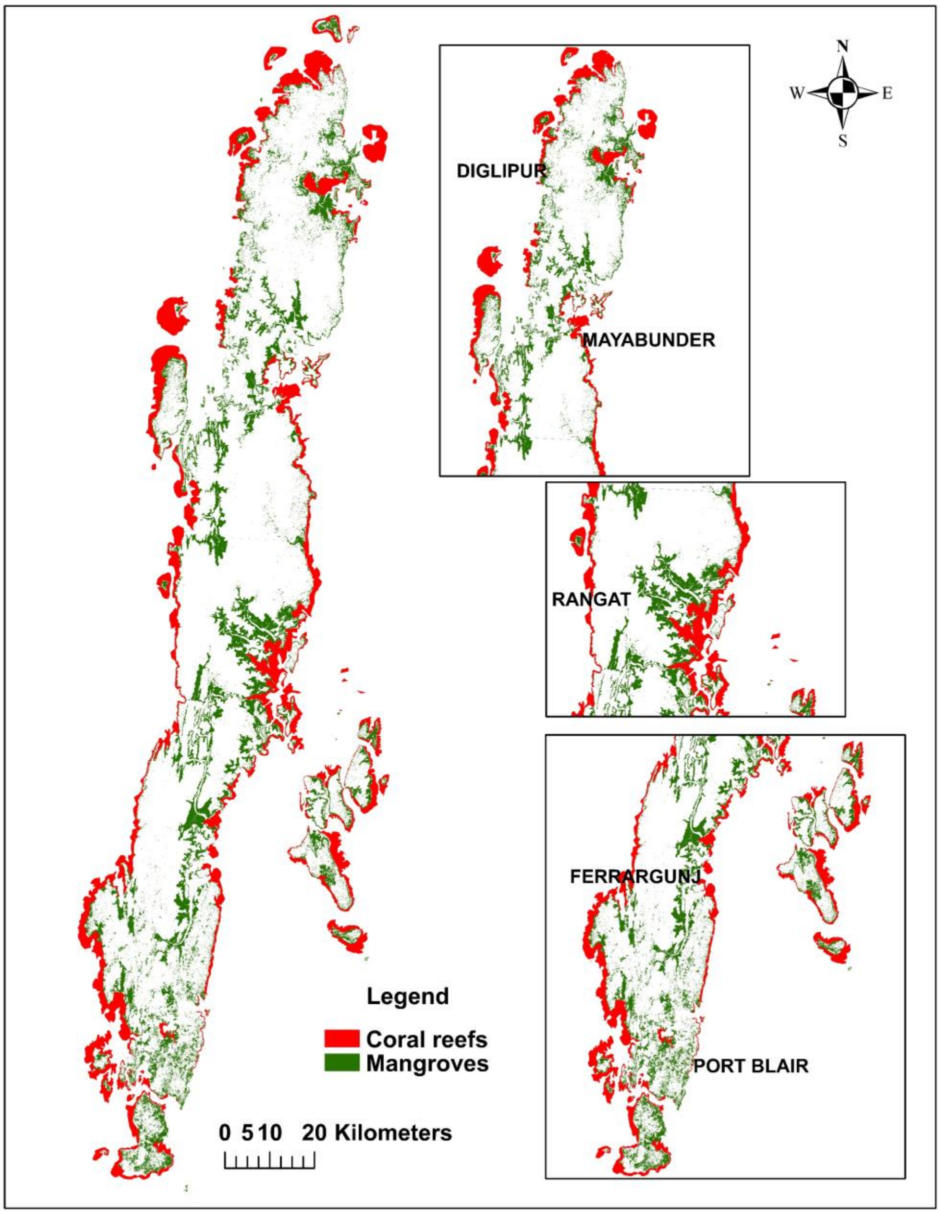


Fig 3.6d. Mangroves and coral reef distribution in Andaman Islands

d. **CORAL REEFS-** Regarding coral reefs, the Andaman Islands are positioned in the north-west section of the Coral Triangle, bordered by the central and eastern regions of Indonesia, the Philippines, and the northern and eastern parts of Papua New Guinea. Fig 3.6d represents coral reef and mangroves distribution of Andaman Islands plotted using the techniques as described in Chapter 2 sections 2.5.4 and 2.5.5 respectively. The island has a total reef area of 1026.46 square kilometers (Mondal et al., 2019) and boasts a rich diversity of approximately 424 species of both zooxanthellate and azooxanthellate corals (Jeyabaskaran, 2007). Similar to other prominent Indo-Pacific coral regions, Andaman Island features large corals such as Favia, Favites, Platygyra, Goniastrea, Diploastrea sp., and Porites sp. Additionally, branching coral species include Pocillopora, Stylophora, Seriatopora, Acropora sp., and Montipora sp., while foliose forms are represented by Montipora foliosa and Echinopora lamellosa. Moreover, non-scleractinian corals, including Heliopora coerulea, Millepora platyphylla, and Tubipora musica, are also plentiful in the Andaman region (Pillai, 1983)

3.7 Demographic Profile of Andaman and Nicobar Island

The population of the Andaman and Nicobar Islands is 3,80,581 (Census,2011). The populace has increased by 9.94 percent over the last decade (between 2001 and 2011) while in Port Blair there has been an increase of 8.05 percent as shown in Fig 3.7. (Basic Statistics,2023 Directorate of Economics and Statistics). The male population has grown by 4.85 percent, while the female population has grown by 8.85 percent. The annual growth rate of population is quite high in several tehsils such as Mayabunder (7.85%), Diglipur (0.71%), Ferrargunge (10.17%), and Port Blair (16.47%), while it is negative in Rangat (-5.66%). These figures suggest that there has been a high influx of migrant labourers in the service sector, particularly in tourism and other new economic activities (ibid). The islanders comprise of –

a. Tribes- Sentinelese, Great Andamanese, Onges, and Jarawas, collectively represent only 7.34% of the overall population in the islands (Table 3.7a) (Sharief and Panda, 2017). Regrettably, their numbers are dwindling rapidly. The Great Andamanese and Onges have been moved to Strait Island and Little Andaman, respectively. In contrast, the Sentinelese still inhabit North Sentinel Island, known for their hostility towards outsiders (Sharief and Panda, 2017). The Jarawa tribe occupies a large forest region from South Andaman to the southern part of Middle Andaman, designated as the 'Jarawa Reserve,' covering approximately 647 km². Their population is estimated to be between 250 and 300 individuals, relying on forest resources and marine products for their livelihood, as highlighted by Sharief and Panda in 2017. The Great Andamanese, also referred to as Strait Islanders, depend on government rations supplied by the Department of Tribal Welfare for their survival. Despite appreciating the support provided through various altruistic measures aimed at assimilation, they have become reliant on this assistance. Similar to the Great Andamanese, the Onge have also received government aid for many years (Khatua 2022). Prior to colonization, they engaged in hunting and gathering, moving systematically within their chosen areas of the island. However, due to their declining population, they now face significant competition from settlers in their pursuit of wild pigs (Chandi, 2010). Additionally, they have become more sedentary and rarely venture beyond their settlements (Chandi, 2010). In contrast, the Sentinelese vehemently resist interaction with outsiders and maintain their geographical isolation from the broader archipelago, allowing them to continue their traditional way of life largely unchanged over the centuries (Chandi, 2010)

Table 3.7a. Tribal Population of Andaman and Nicobar Islands (Source: (Directorate of Economics and Statistics,2023).)

Tribal Population	Census Years						
	1951	1961	1971	1981	1991	2001	2011
Andamanese	23	19	24	26	45	43	56
Onge	150	129	112	97	95	96	126
Jarwas		50		100	39		551
Sentinelese	50	500		31	280	240	50
Shompen	20	71	92	223	250	398	237
Nicobarese	11902	13903	17874	21984	26000	28653	27780

b. Non-Tribes- These constitute a liitle more than 90 % of the total population in the Islands, having arrived in 1858 following the establishment of a Penal Colony by the British at Port Blair. Their population saw significant growth after India achieved independence in 1947, as various resettlement schemes were implemented between 1947 and 1980. From 1949 to 1952, a plan aimed at resettling displaced agricultural populations from East Pakistan (now Bangladesh) was put into action on the Andaman and Nicobar archipelago. This colonization initiative resulted in approximately 450 refugee families being settled on around 3,000 acres in South Andaman. Additional colonies were established in particularly in the Diglipur where a significant number of people were relocated as part of the government's "colonization and rehabilitation" scheme between 1950 and 1959 (Sen, 2017). Dhingra (2005) observes that since the 1970s, the Islands have experienced unplanned migration wave, especially from Tamil Nadu, Andhra Pradesh and Bihar. This trend may be linked to the increasing demand for migrant labor due to rising construction activities in the region. (EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008).

The population density in the Islands has experienced a substantial rise, increasing from 3 individuals to 46 individuals per square kilometer between 1901 and 2011, according to the 2011 Census. The sex ratio has also improved significantly, rising from 197 females to 922 females for every thousand males during the same period (Table 3.7b i). There are noticeable variations in sex ratio, literacy rate, and employment across the different tehsils (administrative divisions) of the islets. Rangat and Mayabunder report highest sex ratios at 935 females per 1,000 males, followed by Ferrargunge (919) and Diglipur (911) (Census, 2011) (Table 3.7b i). Conversely, lowest sex ratio, with 854 females is recorded in Port Blair. Regarding literacy rates, Port Blair leads with 90.22%, followed by Ferrargunge (87.78%), Mayabunder (86.01%), and Rangat (84.39%). Diglipur has the lowest literacy rate at 82.24%. The highest percentage of non-workers is found in Rangat tehsil, where 64.6% of the population relies on others. In contrast, Port Blair has the lowest dependent population rate at 38.6%. Both Diglipur and Mayabunder are entirely rural, with 42.8% and 32.9% of their populations depending on agriculture, respectively (Census, 2011). In Port Blair, only 19.89% are rural population. According to 2011 Census, North and Middle Andaman district comprises 104 revenue villages, while in South Andaman 99 villages and one municipality are present. A detailed distribution of various demographic attributes across the Andaman Islands is presented in a table below (Table 3.7b ii.), accompanied by appropriate graphical representations (Fig 3.7b ii.).

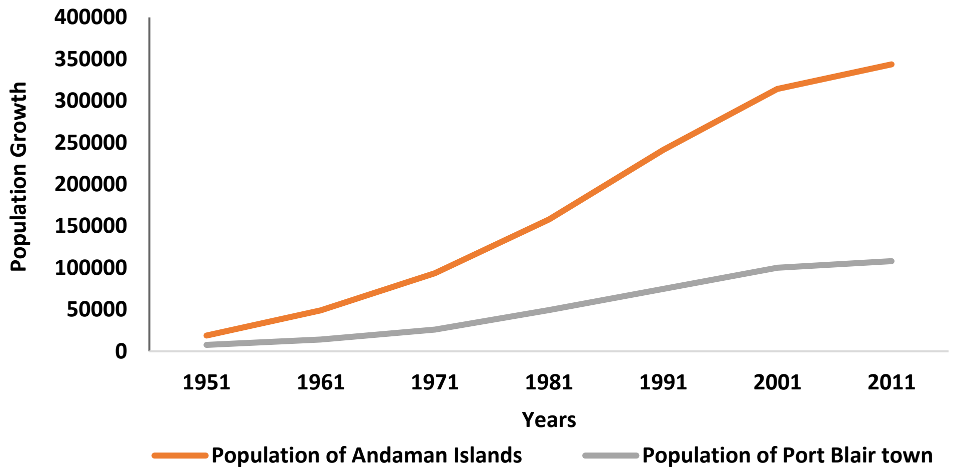


Fig 3.7 Growth of Population in Andaman Island and Port Blair tehsil over the period (1951-2011)

Table 3.7bi. Population Density and Sex Ratio over the period (1901-2011) (Source: Directorate of Economics and Statistics,2023)

Years	Population Density	Sex ratio (No of females per 1000 males)
1901	3	197
1911	3	197
1921	3	146
1931	4	348
1941	4	433
1951	4	489
1961	8	554
1971	14	615
1981	23	750
1991	34	815
2001	43	844
2011	46	922

Table 3.7b ii. Tehsil wise distribution of different demographic attributes of Andaman Islands (Source: Directorate of Economics and Statistics,2023)

Tehsil name	Total Population	Sex ratio (Females per 1000 males)	Urban Population	Rural Population	Female Population	ST Population	Child Population	Illiterate Population
Diglipur	43183	911	0	43183	20584	125	5174	11924

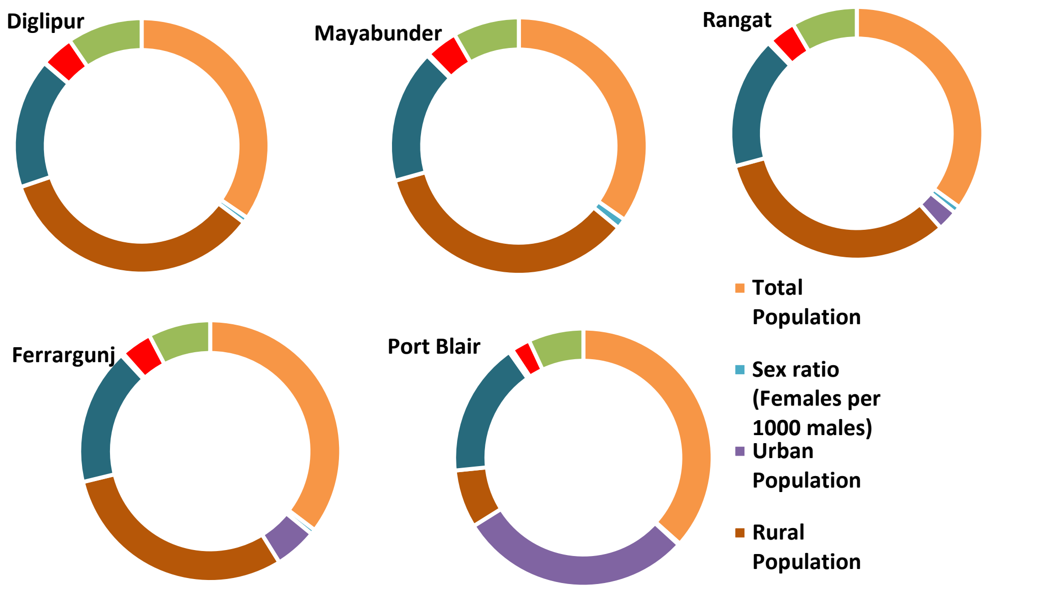


Fig 3.7b ii. Tehsil wise distribution of different demographic attributes of Andaman Island

The District Census Handbook of 2011 clearly indicates that in the North Andaman district, 27.81% of the working population are cultivators, 4.96% are agricultural laborers, 0.67% are involved in household industries, and a substantial 66.56% are engaged in other sectors. In contrast, the South Andaman district shows that only 5.70% of the workforce are cultivators and 2.71% are agricultural laborers, while an overwhelming 90.65% are classified as other workers (Census 2011).

3.8 Economic Profile

During the initial developmental phase of the Islands, the extraction of forest products, played an essential role. By the late 1990s, the annual logging of timber had surpassed

75,000 cubic meters, with 70% of this volume being exported as plywood. This logging activity constituted a significant component of the economy, providing livelihoods and generating revenue for the government until 2002. Currently, approximately 50,000 hectares of land are dedicated to agriculture, with nearly equal proportions allocated to paddy, coconut, and areca nut plantations (Basic Statistics 2021, Directorate of Economics and Statistics). While the service sector contributes 47.50% to the Gross State Domestic Product, the primary sector accounts for 30.0%, and the manufacturing sector contributes a mere 20.0% (EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008).

3.9 Conclusion

The Andaman Islands hold a crucial geopolitical position and possess a unique demographic composition. Their delicate environment and sensitive geology are critical factors that must be acknowledged. With the islands increasingly vulnerable to seismic activity and climate change, it is absolutely vital that these aspects are prioritized in policy and developmental planning. Furthermore, changes in the islands' topography due to tectonic movements must be rigorously integrated into ongoing relief efforts, rehabilitation projects, and future planning initiatives. Understanding these dynamics is essential for effectively addressing present challenges and ensuring sustainable development in the Islands.

CHAPTER-4

BIOPHYSICAL VULNERABILITY ASSESSMENT OF MANGROVES AND CORALS OF ANDAMAN ISLANDS

4.1 Introduction

Mangrove forests maintain health and stability of coastal environments worldwide. However, human activities and natural forces have put pressure on them, making it difficult to serve as shoreline buffers against cyclones and flooding, or as breeding grounds for fish and crustaceans (Makowski and Finkl, 2018). Mangroves' unique characteristics allow them to acclimatize, anaerobic soils, high saline conditions, extreme temperature, strong winds and high tides, (Giri et al., 2011; Kuenzer et al., 2011; Nagelkerken et al., 2008) Besides, these vegetations protect coastal communities against erosion and storms (Blasco et al., 2002). Moreover, being rich biodiversity hotspots, they provide provisioning and cultural services (Mazda et al., 1997; Manson et al., 2005). The mangrove forest cover, has now been reduced to less than 50% of its original extent (Spalding et al. 1997, Vani and Prasad, 2018). Natural disturbances such as hurricanes, tsunamis, storms, and lightning, as well as manmade stresses like aquaculture, farming, and urban development, overexploitation are responsible for the destruction of these species (Reddy et al., 2007). According to recent research estimates, Climate change is expected to significantly impact air and water temperatures, amount of precipitation and intensity of hurricanes and cyclones (Solomon et al., 2007; Alongi, 2002). While mangroves have a natural ability to withstand and recover from these changes, their existence could be greatly compromised when combined with human conflicts (Kandasamy, 2017).

Coral reefs offer many essential ecosystem services, including fisheries, tourism, sand for beaches, and protection from wave erosion. This makes them one of the most valuable marine ecosystems in many countries, according to Turner et al. (2009). These reefs are highly productive yet fragile ecosystems that are primarily found in warm waters of the tropics, where the temperature doesn't fall below 20°C. They are often referred to as the rainforests of tropical seas and are considered keystone ecosystems concerning global climate change (Bahuguna et al., 2008). The World Resources Institute (1998) found that human activities were responsible for the degradation of at least 80% of the reefs in Southeast Asia. The IUCN global status reports that out of 132 threatened species in India, 129 species of scleractinian corals are threatened (118 are vulnerable, 10 are endangered, and 1 is at risk of extinction). Therefore, there is an urgent need for a global monitoring system to track the responses of mangroves and corals to climate change (Field, 1995).

4.2 Mangroves of Andaman

Following West Bengal and Gujarat, the Andaman Islands is the third largest State in terms of mangrove coverage containing approximately 12.4% (616 km²) of total mangrove area, (FSI, 2021). A study by Raghavan et al. (2018) identified the highest diversity of mangrove species in South Andaman, with 30 species recorded, tailed by Diglipur and Mayabunder each with 25, Nicobar with 21, and both Little Andaman and Havelock with 20 species each, along with Baratang also having 20 species. The water seepage into the creek edges and shorelines introduces additional fresh water, which, when combined with saline water, creates an ideal habitat for mangrove growth (Paul et al., 2018). The calcium carbonate-rich sediments and various bioclasts with bio-encrusted surfaces, combined with the relatively sheltered shores, low tidal range of 0.50-1.00m, substantial wave heights exceeding 1.5m, saltwater influences, and an average annual rainfall of 3000mm significantly boost the dense growth of mangroves (Paul et al., 2018).

4.3 Corals of Andaman

The coral shelves of Andaman Islands, are home to around 80% of the global coral diversity (Venkataraman, 2011). 569 species of scleractinian corals, have been reported from these areas (Mondal and Raghunathan, 2018). In these Islands, the reef flat extends up to 500 meters from the shore and sometimes merge with submerged reefs towards the sea in areas like Wandoor National Park, Taramughli Island, North Reef Island, etc (Coastal Zones of India, 2012). The reefs around Interview and Twins Islands showcase a diverse coralline shelf, while Havelock Island features an exposed reef slope, highlighting the variety of marine ecosystems in the region. Neil Island presents the outermost section of the reef area, encompassing both the reef slope and the reef front (Coastal Zones of India, 2012). Dam Roy and George (2010) note that the edges of the reef platform support a robust growth of corals, with notable species including Porites, Favia, Pocillopora, and Acropora. Additionally, Bandopadhyay and Carter (2017) observed that the western coast boasts a richer diversity of coral growth compared to the eastern coast. This information underscores the importance of protecting these unique marine habitats for future conservation and research efforts.

Mangrove ecosystems support the growth of corals and seagrasses, as shown by studies such as Bastos et al. (2022). Mangrove ecosystems have a positive interaction with seagrass meadows because the roots of mangroves capture and filter out fine sediments from water, thus protecting reefs and seagrass ecosystems (Mishra and Apte,2020; Jordan and Fröhle,2022). On the other hand, the calm conditions created by coral reefs enhance the accumulation of deposits promoting the growth of mangroves and sea grass beds (Watanabe and Nakamura,2019). Furthermore, both corals and seagrasses play a vital role in creating carbon sinks by balancing all forms of carbon levels in coastal regions (Akhand et al.,2021). It is essential to preserve these interconnected ecosystems for storing and exporting blue carbon in tropical coastal regions (Lovelock, 2020).

The Andaman Islands, like many other island ecosystems, are at risk of experiencing natural disasters like storms, tsunamis, earthquakes, and cyclones that can have adverse effects on the unique association of mangrove and coral ecosystems. In addition, anthropogenic land-use change also poses a threat to these ecosystems (Mageswaran et al., 2021). While previous studies have explored the future suitability of these forests, there has been limited research on identifying areas where mangroves and corals are vulnerable, particularly within the framework of the IPCC AR4. Therefore, it is crucial to identify these vulnerable zones and come up with strategies to mitigate threats, to manage and protect these delicate ecosystems effectively.

The study focused on exploring the threats experienced by the reefs, specifically examining key factors that determine their distribution. Additionally, the study assessed the sensitivity of these corals to various stressors and the potential impacts of these factors, considering the exposure to stress. It also included a measure of the potential impact, which may or may not be mitigated by the adaptive capacity of corals or other critical components of coral reefs.

4.4 Methodology

The methodological frameworks for Biophysical Vulnerability of mangroves and corals of Andaman Islands have been designed based on the IPCC AR4 working definitions. The vulnerability index has been constructed at the tehsil level using the Min-max rescaling transformation. The details of the index and the estimation of various parameters have been discussed in Chapter 2 Section 2.5.2-2.5.8.

4.5 Results

4.5.1 Mangrove Forest Health Assessment

The technique adopted to assess the health of Andaman mangroves was discussed in section 2.6.5 of Chapter 2. The composite stress map representing the health of the mangrove forest (1990-2018) in Andaman Island is presented in Fig 4.5.1. When the Vegetation Condition Index (VCI) ranged from zero to one hundred and the NDVI increased, it suggested healthy vegetation with high chlorophyll content, however when the VCI quantified less than zero and the NDVI decreased, it indicated vegetation stress and less chlorophyll content. Mangrove forests in all the locations registered significant degradation in the year 2005 due to aftermath of Tsunami and slowly regained health in 2015 and 2018.

4.5.2 Land cover and Land use analysis

The study clearly provided a thorough analysis of LULC changes over time using appropriate techniques as mentioned in Chapter 2 section 2.6.3 (Fig 4.5.2a). The classification results were impressive, showing an accurateness of 84% (kappa coefficient = 0.73) in 1993, 82% (kappa coefficient = 0.74) in 2010, and an improved 86% (kappa coefficient = 0.76) in 2018. Additionally, aereal changes in land cover and land use during the periods of 1993, 2010, and 2018 are clearly laid out in a table (Table 4.5.2).

- **Non-mangrove forests and Shrubs**- According to satellite image interpretation, from 1993 to 2018, there was an increase of about 9214.3 sq. km in shrubs, while non-mangrove forests suffered a significant loss of 10065.3 sq. km. Although Diglipur tehsil witnessed increase in forest area by 337.6 sq. kms, Port Blair and Ferrargunj tehsils of South Andaman suffered a joint loss of 9051.5 sq. km in non-mangrove forests (Fig 4.5.2b).

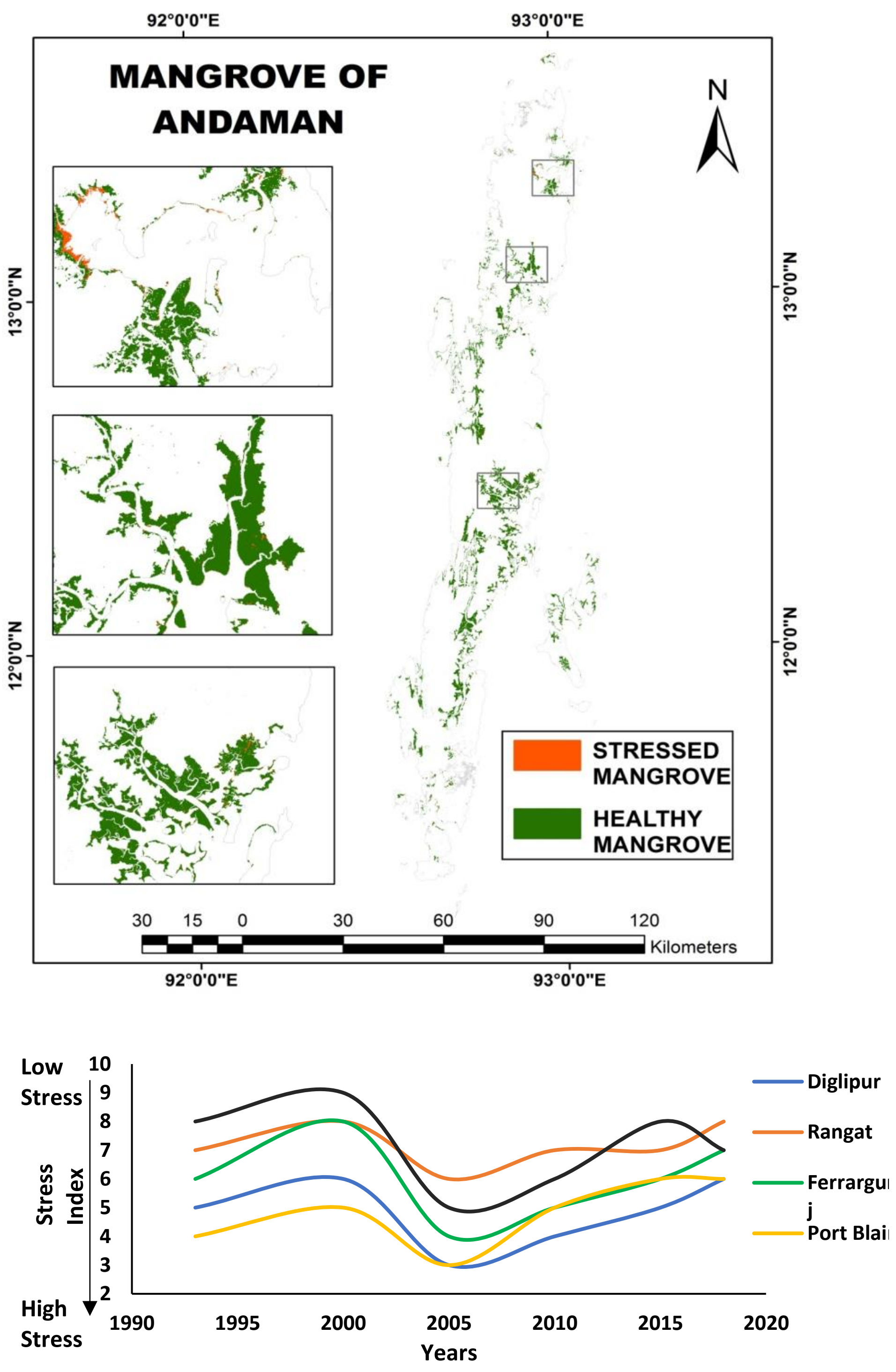


Fig 4.5.1 Tehsil wise presentation of mangrove health in Andaman Islands

- **Mangrove forest**- Between 1993 and 2010, mangroves lost a total of 840 square kilometres, while from 1993 to 2018, a reduction of about 717.0 square kilometres of mangrove cover was recorded. The North Andaman Tsunami caused considerable damage to vast tracts of dense mangroves, resulting in the loss of a mangrove patch of 946.3 square kilometres in Diglipur and 179.6 square kilometres in Mayabunder. In Diglipur and Mayabunder, areas of dense mangroves were replaced by open mangroves between 1993 and 2018. Rangat, Port Blair, and Ferrargunj, on the other hand, recorded a combined increase in mangrove extent of 226.0 square kilometres.
- **Mudflats-** According to a classification report from 1993, the extent of mudflats was 3576.8 sq. km. However, by 2010, it had drastically reduced to 1101.5 sq. km. During the same year, Diglipur had the highest loss of mudflat with 837 sq. km, followed by Rangat (533 sq. km), Mayabunder (408.4 sq. km), Port Blair (385.3 sq. km) and Ferrargunj (310.6 sq. km). In 2018, mudflats increased significantly in Diglipur and Ferrargunj. by 1011.6 sq. km, and 445.8 sq. kms respectively (Fig 4.5.2b).
- **Coral reefs-** The western coast is home to thriving, abundant coral reefs, while the eastern coast only features narrow fringing reefs situated adjacent to the shores. In 1993, 2010, and 2018, coral reefs spanning 1208.66, 829.64 and 1001.85 square kilometres, respectively, were mapped and compared to land cover maps of the same years. The technique for coral mapping was discussed in detail in Chapter 2, Section 2.5.4. The land cover map showed that reef degradation of approximately 220 square kilometres occurred in South Andaman in 2010, followed by Mayabunder, Rangat, and Diglipur (Fig 4.4.2b). However, there was a significant recovery of reef extent after the Tsunami, as evidenced by an increase in their extent in each tehsil
- **Sandy Beach-** In 2018, the total area covered by the beaches was 600 sq. km (see Fig 4.4.2b). However, these beaches face natural calamities like tsunamis, cyclones, and coastal erosion, which cause significant damage (Yuvaraj et al, 2012). Additionally, human activities, such as sand mining, pose a major threat to these beaches, leading to their loss over time (Andrews and Vasumathi, 2002).

Table 4.5.2 Temporal changes in LULC in various tehsils of Andaman Islands over the years 1993,2010 and 2018

Years	LULC	Diglipur	Mayabunder	Rangat	Port Blaire	Ferrargunge
1993	Shrubs	5863.10	2791.11783	3720.50	1134.05	1654.86
	Mudflats	1360.72	502.41720	719.51	486.67	507.47
	Mangroves	1963.90	7,048.68	1651.04	512.69	1028.05
	Coral reefs	89.007	247.91184	95.75	203.11	572.8
	Sandy beach	82.80	32.53294	5.28	8.26	4.27
	Vegetation	3570.99	3086.04315	511.55	279.65	807.80
	Urban Built up	0.00	0.00000	138.53	305.42	0.00
	Agricultural land with settlements	412.90	256.55928	313.44	205.30	254.66
	Fallow land	357.57	167.69472	153.92	49.61	127.83
2010	Shrubs	4077.90	1984.11000	2383.78	1288.16	1152.15
	Mudflats	523.30	93.99160	186.19	101.41	196.90
	Mangroves	1017.65	5252.65000	1727.15	625.59	1124.42
	Coral reefs	54.93	200.115	42.3	104.47	427.80
	Sandy beach	59.12	40.14290	11.59	24.91	15.50
	Vegetation	7011.83	4612.34000	6743.33	2414.37	8582.93
	Urban Built up	0.00	0.00000	84.65	204.75	0.00
	Agricultural land with settlements	498.18	272.55500	274.83	300.95	258.84
	Fallow land	379.40	185.52060	144.12	46.75	71.16
2018	Shrubs	5889.4	331.24492	483.04	283.44	751.13
	Mudflats	1534.62	415.38583	578.53	401.62	642.75
	Mangroves	1201.53	5243.00650	1684.38	594.43	1138.93
	Coral reefs	101.21	30.30163	38.81	780.53	51.0
	Sandy beach	218.72	67.92516	8.91	14.09	83.71
	Vegetation	3908.58	2720.14992	4130.00	1645.62	1773.83
	Urban Built up	34.67	0.00000	428.47400	555.51	158.88
	Agricultural land with settlements	995.34	555.56498	501.80	498.50	462.17
	Fallow land	0.00	0.00000	0.00	0.00	0.00

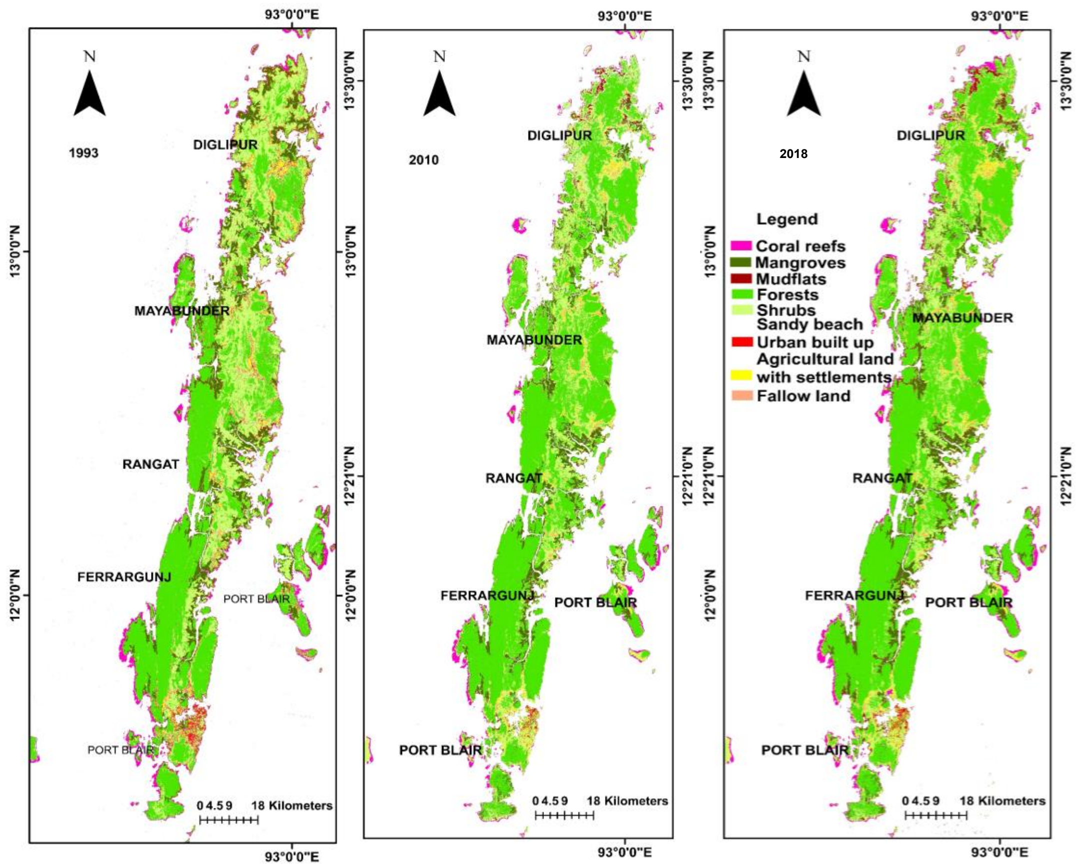


Fig 4.5.2a Land use and Land cover presentation of Andaman Islands of the years 1993,2010 and 2018

- **Agriculture with settlement-** Compared to other parts of the Andaman Islands, South Andaman showed fewer agricultural practices, which have slowly decreased due to urbanization. Currently, it occupies an area of only 96 sq. km, according to the table. The agricultural land with settlement gradually increased from 1440 sq. kms to 1600 sq. km from 1993 to 2010. In 2018, it recorded an area of 3000 sq. km. The cultivation of crops includes paddy, pulses, oilseeds, and vegetables. Most of the agricultural activities in the Andaman Islands are practised in flat terrains and low-lying areas of Diglipur (995 sq. km) followed by Mayabunder (555.6 sq. km) (Fig 4.5.2c)

- **Urban built-up-** Over the last three decades, there has been a gradual increase in urban agglomerations and infrastructure developments nucleating around the Port Blair tehsil of South Andaman Islands (Fig 4.5.2c). This development has mainly occurred in the coastal areas where resources are available for economic growth.

As a result, there has been an extension of land use every year, putting stress on forests, mangroves, and sandy beaches.

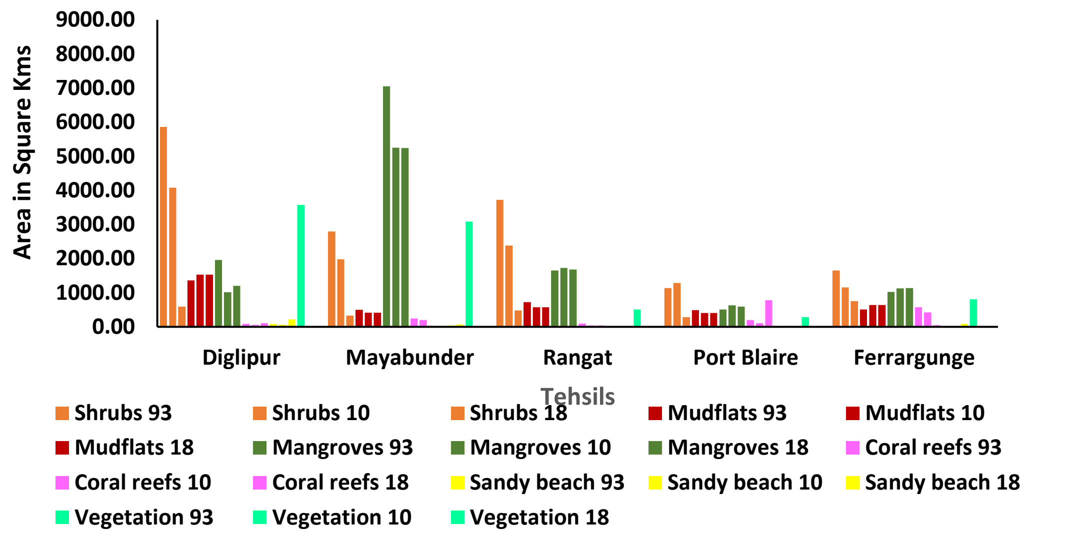


Fig 4.5.2b Temporal change in Land cover statistics of each tehsil of Andaman Islands

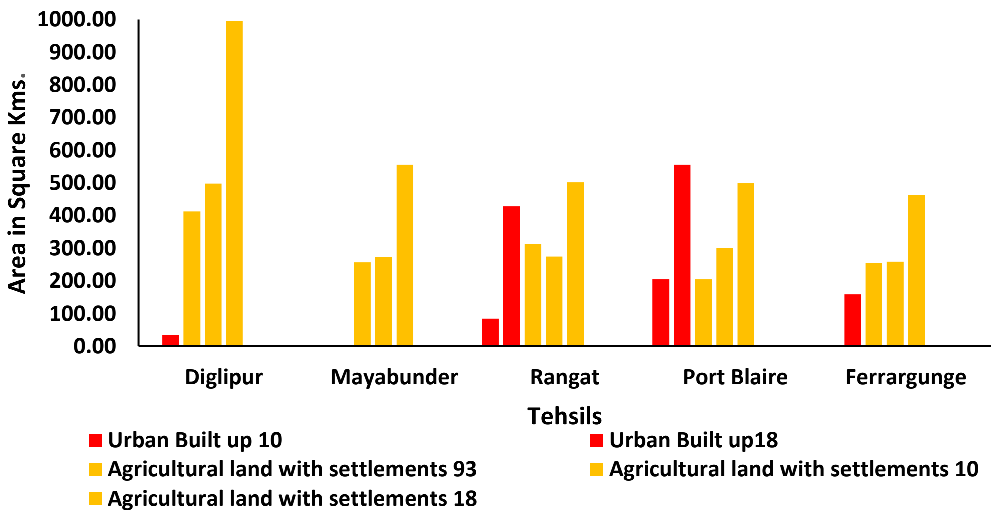


Fig 4.5.2c Temporal change in Land use statistics of each tehsil of Andaman Islands

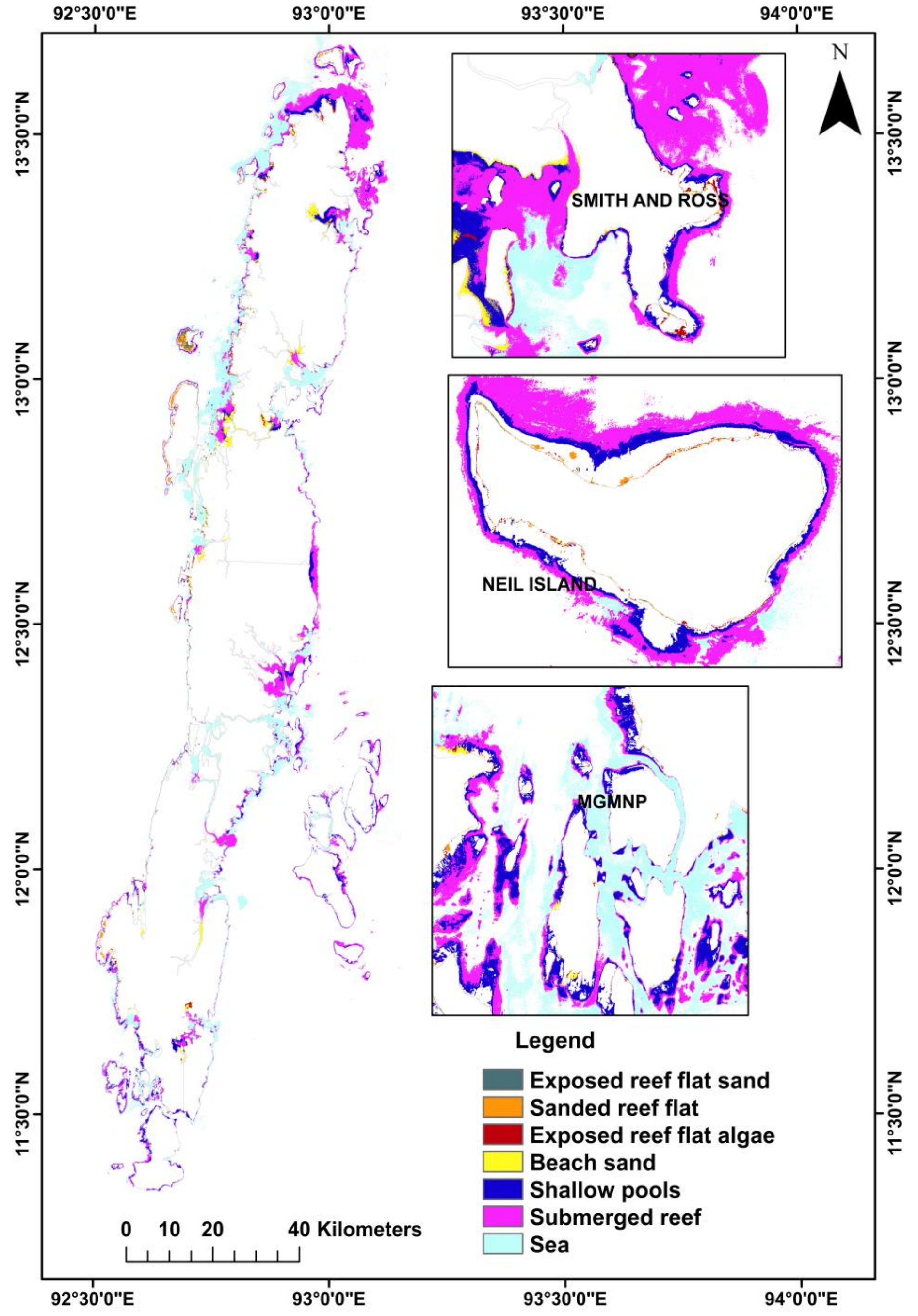


Fig 4.5.3 Coral eco-morphological zones of Andaman Islands

4.5.3 Coral reef mapping

The classification results of eco morphological zones of the Andaman corals showed an accuracy of 92% (kappa coefficient = 0.79). The type of reefs found in the Islands are 1. Reef Flat with sand, 2. Exposed reef flat covered with algae and 3.

exposed reef flat with sand, 4. shallow pool category, 5. Submerged Reefs and 6. Beach sands (Fig. 4.5.3). Submerged reefs were primarily prevalent in Taramugli Island, North Reef and East Islands Furthermore, existence of deeper reef platforms was documented in Boat, Jollybouys, and North Sentinel Islands.

The 2004 earthquake caused significant elevation changes, including subsidence in some areas and uplift in others. The coral environment was greatly affected, with observed changes in the coral reefs. Heavy damage to coral reefs was observed on North Reef and Interview Islands, with subsequent sand deposition and algal growth over exposed reef flats. Reefs were found exposed and dead along the northwestern coasts of Andaman, Sentinel Island, and the west coast of Rutland and Little Andaman Islands.

4.5.4 Flood inundation mapping

To identify areas of varying tsunami vulnerability—high, moderate, and low threat zones—elevation data from the Shuttle Radar Topography Mission (SRTM) was utilized. A manual classification of the elevation values in ArcMap effectively provided a visual representation of the regions categorized into these different threat levels. Three levels of flood inundation risk were identified based on land elevation (Fig 4.5.4) within the inundated area, as follows:

- High threat: Areas with an elevation of 2-4 meters were placed in the high threat category based on Tsunami run-up height calculations. These low-lying areas face the most significant threat of inundation by Tsunami. Approximately 0.40% of the land falls under this category.
- Moderate threat: This zone includes parts of land with an elevation ranging upto 6.0 meters above MSL. These areas would face the threat of flooding only if Tsunami run up height reaches 4 meters or above. 3.2% of the total inundated area falls in this zone.
- Low threat: 96.38 % of the land falls in this high-elevation zone of the Islands,

A further assessment of mangrove and coral classification within the flood prone regions was done to deduce the threat areas. The assessment revealed that Rangat accounts for the highest threat with 30.82 %of mangroves falling under the flood risk zone, followed by Port Blair (21.83%), Ferrargunj (17.87 %), Mayabunder (16.58 %), and Diglipur with only 11.60 % of mangroves under flood inundation zone accounts for the lowest threat. In terms of the percentage of coral reefs under inundation zones Diglipur and Ferrargunj ranked highest and second highest (33.65 and 24.32% respectively) whereas Port Blair and Rangat had the least vulnerability where only 19.95 and 19.74 % of reefs fall under inundation risk zones

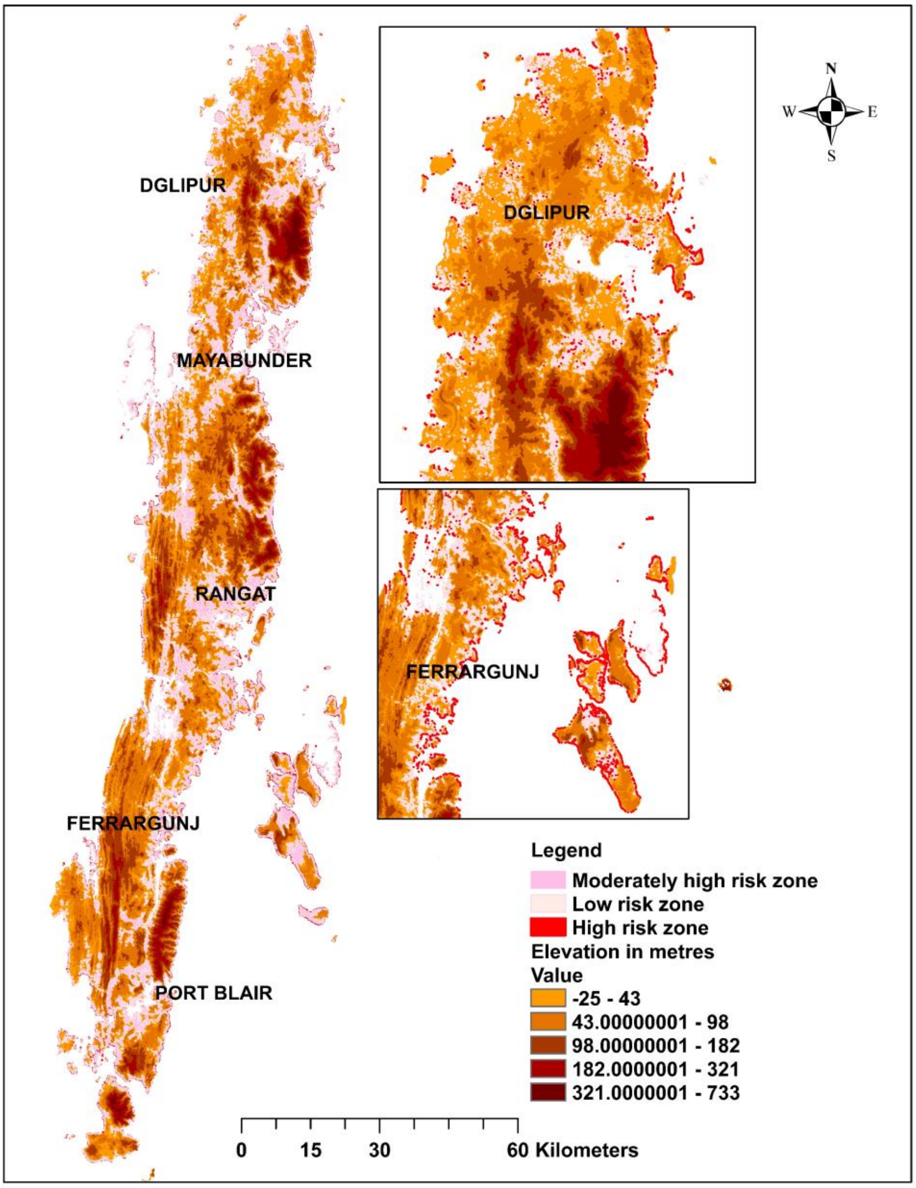


Fig 4.5.4 Flood inundation risk zones of Andaman Islands based on land elevation

4.5.5 Seaward Edge Retreat

By entirely depending upon secondary data, erosion and accretion rate of various study regions of Andaman were documented. Following the study of Mondal et al (2024) on coastal and mangrove vulnerability in Andaman, Ferrargunj and Port Blair were found to be more susceptible to erosion, with an average shoreline change rate of -6.830 m/y and -2.530m/y, respectively. The mangrove stratigraphy in Diglipur, was found to have net accretion rates of +1.4 m/y both landward and seaward. Moreover, with 0.7m/y and 0.63m/y Mayabunder and Rangat, exhibited positive deposition rate respectively. Therefore, North Andaman showed the highest rate of deposit at 55.68 m/y, while South Andaman recorded the highest rate of retreat at -62.27 m/y.

4.5.6 Relationship between Mangrove Biophysical Parameters and Climatic Variables.

Rainfall has a close association with various biophysical parameters of mangroves such that any alterations in these parametres can upset the function of these habitats (Kumar et al., 2017; Rodriguez et al., 2016). Rainfall is substantial, with an average of about 3035 mm annually, primarily concentrated between May and December. The southwest monsoon asserts its dominance with heavy rainfall from late May to early October, while the northeast monsoon contributes a lighter, yet still significant, rainfall from November to December (Balasubramaniam et al.,2017). Figure 4.5.6 illustrates the seasonal average rainfall trend analysis for Andaman Island over the period from 1998 to 2018, utilizing data obtained from the TRMM platform. The monsoon regime of the island is categorized into three distinct phases: the pre-monsoon, monsoon, and post-monsoon seasons, as depicted in the figure. Notably, both the monsoon and post-monsoon seasons exhibit an increasing trend in precipitation levels, whereas the pre-monsoon period reflects a comparatively lower trend in rainfall. This analysis confirms the findings of Barik et al. (2018) that during the pre-monsoon seasons, decreased freshwater flow and increased evaporation lead to higher soil salinity, while this situation reverses in the rainy seasons and winter. The Diglipur and Mayabunder tehsils experience more variation in climatic parameters compared to Ferrargunj and Port Blair over time. The salinity variation in coastal wetland regions is determined by seasonal precipitation and evapotranspiration patterns, tidal regimes, and river dynamics. (Barik et al, 2018). Insufficient rainfall leads to elevated salinity, which significantly hampers mangrove productivity and growth. In contrast, increased precipitation effectively lowers salinity, resulting in enhanced productivity and growth of these vital ecosystems (Upadhyay and Mishra, 2010). These processes facilitate the accretion of land and actively promote the migration of mangroves to newly formed areas (Harty, 2004; Upadhyay and Mishra, 2010). It's worth noting that the mangrove soils of Andaman are naturally saline. The physical parameters in mangrove habitat region exhibits pH range between 7.96±0.03 to 7.97±0.05, whereas salinity varies from 31.48±0.02 to 31.50±0.03 (Mishra and Manish,2018). In the summer months, water loss from the land surface by evapotranspiration is easily replenished by the saline tidal waters from the creeks. However, during the rainy season, areas far away from the creeks tolerate higher salinity and acidity with salt crusts at the surface. This is because the loss of water by evapotranspiration exceeds the amount of replenishment by tidal waters (Dagar et al, 1993). All tehsils, except Ferrargunj and Port Blair, experienced significantly higher rainfall during monsoon and post-monsoon seasons compared to pre-monsoon precipitation. Creeks in South Andaman that are funnel-shaped experience a decrease in tidal amplitude and salinity as one moves from the seaward fringes to the landward sub-tidal creeks. This arrangement provides a large habitat for mangroves, as described in studies conducted by Yuvraj et al. (2014 and 2017). According to the study conducted by Mishra and Manish (2018), temperature range at site with mangroves 30.63 to 30.66°C. The relative humidity measurements had a precision of 60-85%, whereas specific humidity had a precision of approximately 60%.

Coastal vegetation can attain its highest level of succession with low to moderate wind speeds. However, high windspeed can negatively impact growth (Alongi, 2008). In this study, it was found that wind speeds between 5.57 and 5.69 m/s, facilitated stabilization of vegetation. Major region controlling unsuitable conditions for mangrove growth was affected by moderate, moderately high and high wind speeds, which accounted for 23.27%, 30.63%, and 15.84% respectively. Additionally, an increase in storm intensity, determined by current speed, influences the location of mangroves concerning the wind field and gap recruitment. (Alongi, 2008)

Tides are crucial for the growth and survival of mangroves. They help to distribute nutrients, flush out waste, and make the substratum permeable for nourishment of mangroves (Ramakrishnan et al.,2020). In the specific case of the Andaman region, the tidal range was measured to be 2.4 m, while the sea surface height was 7.37 mm. The findings of this study align with the reasoning presented by Dwarakish et al. (2008) and Gorokhovich et al. (2014). Specifically, it suggests that a greater tidal range correlates with reduced vulnerability, while a smaller tidal range corresponds to increased vulnerability. This relationship underscores the importance of tidal dynamics in assessing vulnerability levels in coastal environments. Apart from climatic variables, the distribution of mangroves is also controlled by high elevation and slope. The elevation ranges from 4m to 517m, with the majority of the area (87.40%) lying within 18m from the ocean level.

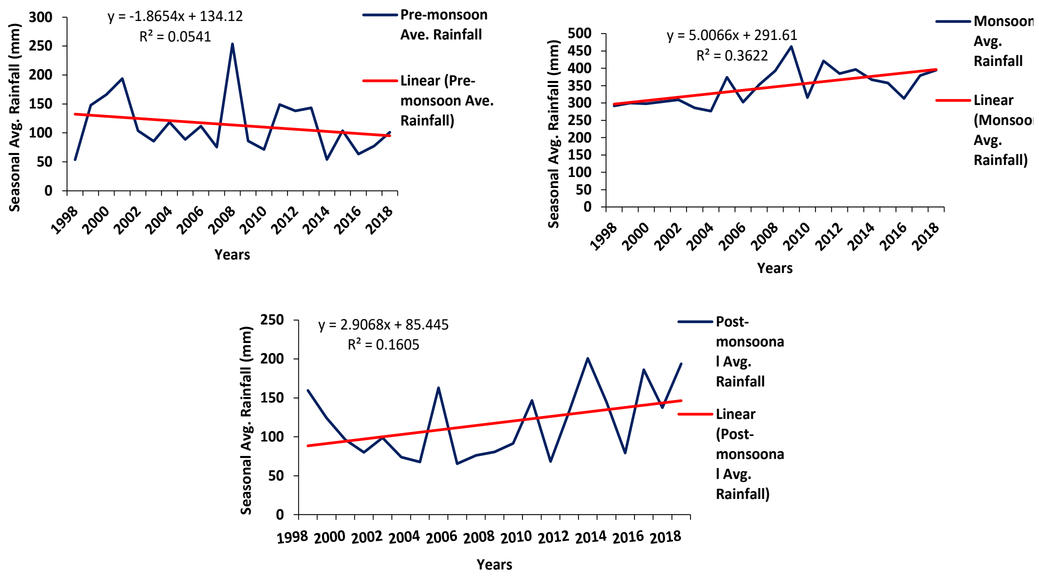


Fig 4.5.6 TRMM seasonal average rainfall trend analysis of Andaman Island over the period (1998-2018).

4.5.7 Identification of Vulnerable Mangrove Areas

Each tehsil was ranked into one of five categories of VI scores: very high vulnerability (Rank 5), high (Rank 4), moderate (Rank 3), low (Rank 2), and very low vulnerability (Rank 1) (as shown in Table 4.5.7). Based on scores, a vulnerability map was created in Arc GIS 10.5. The map was produced using classification techniques,

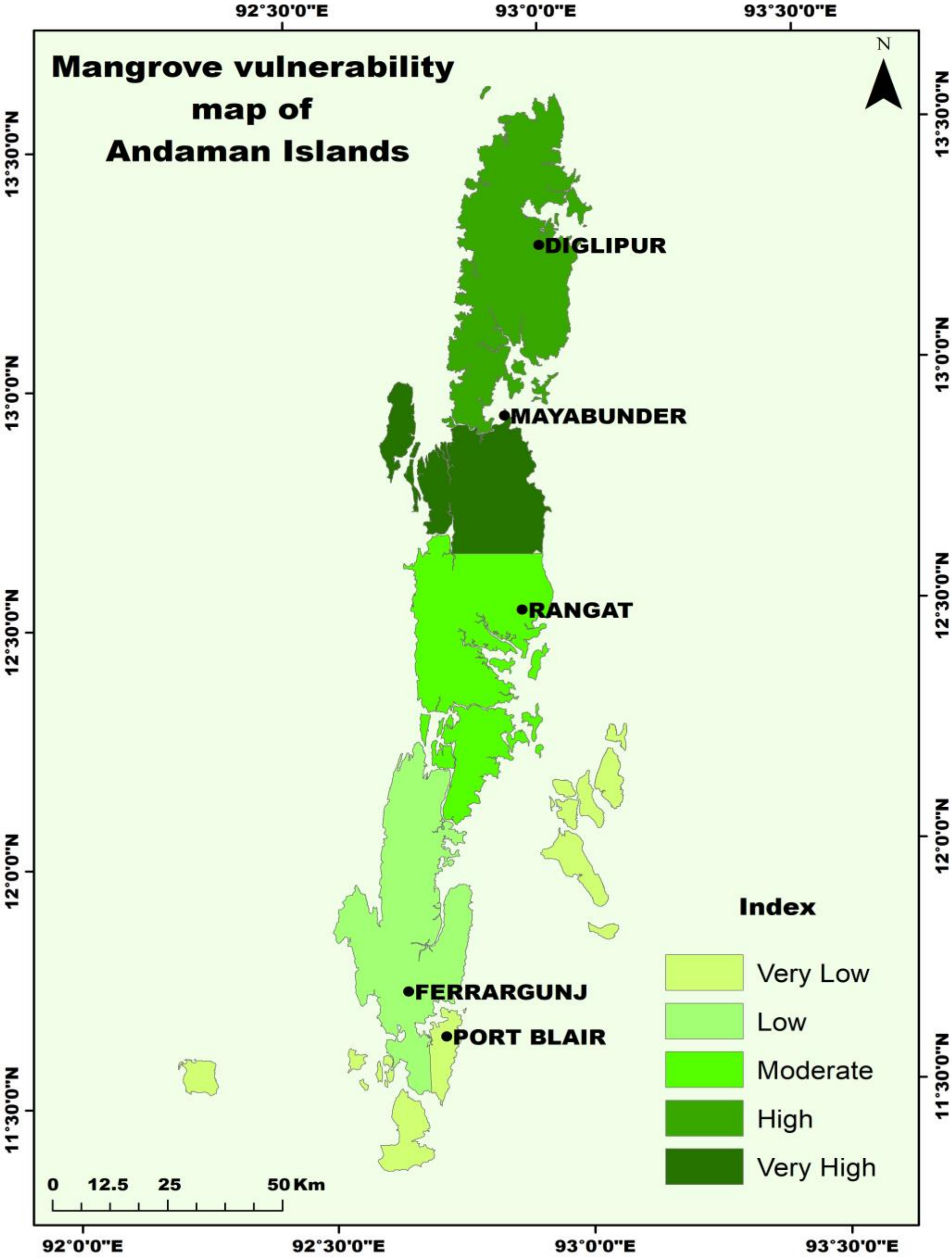


Fig 4.5.7 Mangrove vulnerability ranking of each tehsil of Andaman Islands based on IPCC AR4 framework

which ranked each tehsil according to its level of vulnerability. The results showed that Mayabunder and Diglipur registered very high and high vulnerability ranking respectively. Ferrargunj and Port Blair, on the other hand, were ranked as having low and very low vulnerability rankings (Fig 4.5.7). In Rangat, the mangroves were found

Table 4.5.7 Results of different variables after Min-Max Rescaling and final mangrove vulnerability calculation

Contributing Factors	Variables	Diglipur	Mayabunder	Rangat	Port Blair	Ferrargunj
Exposure	Relative Humidity	0.96	0.87	0.72	0.28	0.37
	Specific Humidity	0.71	0.67	0.80	0.36	0.39
	Temperature	0.06	0.15	0.40	0.79	0.69
	Current Speed	0.65	0.67	0.83	0.38	0.44
	Earth Skin Temperature	0.03	0.02	0.13	0.69	0.56
	Wind Speed	0.87	0.68	0.44	0.16	0.26
	Wind Direction	0.91	0.76	0.25	0.30	0.23
	Pre-Monsoon Rainfall	0.12	0.21	0.28	0.71	0.80
	Monsoon Rainfall	0.87	0.63	0.30	0.13	0.17
	Post Monsoon Rainfall	0.85	0.96	0.52	0.58	0.49
	Sea Surface Temperature	0.44	0.89	0.93	0.39	0.64
	Tide	0.62	0.96	0.89	0.57	0.57
	Sea Surface Height	0.49	0.99	0.99	0.40	0.67
	Exposure	0.58	0.65	0.58	0.44	0.48
Sensitivity	Mangrove Health	-0.7121	-0.9650	-0.9788	-0.8857	-0.9772
	Mangrove reduction	1.00	0.66	0.00	0.00	0.00
	% Loss of mudflat	0.00	0.88	1.00	0.89	0.00
	Erosion	0.00	0.00	0.06	0.01	0.33
	Accretion	0.16	0.05	0.03	0.00	0.01
	Mangrove at risk of inundation	0.00	0.26	1.00	0.53	0.33
	Salinity	0.73	0.97	0.98	0.90	0.97
	Elevation	-0.24	-0.19	-0.48	-0.40	-0.38
	Sensitivity	0.12	0.21	0.20	0.13	0.04
Adaptive Capacity	%mangrove regeneration	0.00	0.00	0.57	0.73	1.00
	% Regeneration of mudflat	0.48	0.00	0.00	0.00	1.00
	Marine Protected Areas	0.50	0.50	1.00	1.00	0.00
	Adaptive Capacity	0.33	0.17	0.52	0.58	0.67
	VI	0.030	0.101	0.011	-0.018	-0.007
	RANK	4	5	3	1	2

to have a moderate vulnerability due to the presence of protected forests and coastal mangrove swamps. It was also noted that mangroves along the creeks were more vulnerable to coastal erosion than those near the shore. The multihazard data assessment indicated that Mayabunder and Diglipur were at the highest risk of climate threats, followed by Port Blair and Rangat. However, regarding coping mechanisms for stressors, Ferrargunj outperformed the other tehsils and was therefore ranked as having low vulnerability.

4.6 Vulnerability of Andaman coral reefs to Climate Change

Worldwide reefs have experienced widespread bleaching and mortality (Heron et al., 2016; Heron et al.,2018; NASEM, 2019). Lately, urban developments have resulted in higher sediment levels, and increased pollutant levels, all of which have stalled reef growth and even lead to the disappearance of coral communities from reefs (Veron,2000; McCulloch et al.,2003; Wachenfeld, 1997). Storm frequency and intensity also impact coral reefs by dislocating them from certain areas. (Hoegh Hoegh Guldberg O et al.,2007). The 1998 coral bleaching event led to a momentous decay of live corals in major reef area of India (Arthur, 2000; Muley et al., 2002). The corals of the Andaman Island face grave threat from coral bleaching, earthquakes, tsunamis, as well as human-induced threats including siltation, sedimentation, sand mining for construction, deforestation, unsustainable fishing, and pollution (Jeyabaskaran, 2007; Majumdar et al.,2018).

4.6.1 Changes in water temperature

The evaluation of sea surface temperature (SST) trends was categorized into three distinct phases: pre-monsoon, monsoon, and post-monsoon (Fig 4.6.1). While it is observed that sea surface temperatures decrease during the post-monsoon season due to heavy rainfall, the average temperatures during the pre-monsoon and monsoon phases display a notable upward trend. This trend presents valuable opportunities for further research into its implications for marine ecosystems, especially coral reefs, which may experience pigment loss as a consequence (Majumdar et al., 2018). Monthly comparison analysis of sea surface temperatures (SST) in 2030, 2050, and 2080 revealed that the highest increase in SST occurs in April and May, leading to bleaching temperatures lasting for more than three days (as discussed in Chapter 6, Section 6.9. While the period from 2001 to 2010 saw the highest number of bleaching events, the frequency of these events could vary from 4 to 5 in the upcoming years.

Coral bleaching is the most drastic outcome of corals being exposed to higher temperatures than they can tolerate. During coral bleaching, the corals lose the brown colouration provided by their dinoflagellate symbionts. The occurrence of mass coral bleaching events is closely linked to warmer-than-usual conditions. It is possible to predict mass bleaching events by monitoring SST anomalies or by analysing time-temperature curves (Berkelmans, 2002; Hegh Hoegh Guldberg O,2004). Corals are sensitive to light thus shaded corals do not bleach profusely as those well-lit (Anthony et al., 2007; Jones and Hoegh Guldberg O, 1999; Mumby et al., 2001). The flow of water (Nakamura et al., 2004) can significantly affect the photosynthetic performance of zooxanthellae inside the coral (Ulstrup et al., 2005). Bleaching doesn't necessarily result in death of the coral. If the level of thermal stress is mild and temporary, bleached corals may recover their symbiote although the process can take several months (Hoegh Guldberg O et al.,2007).

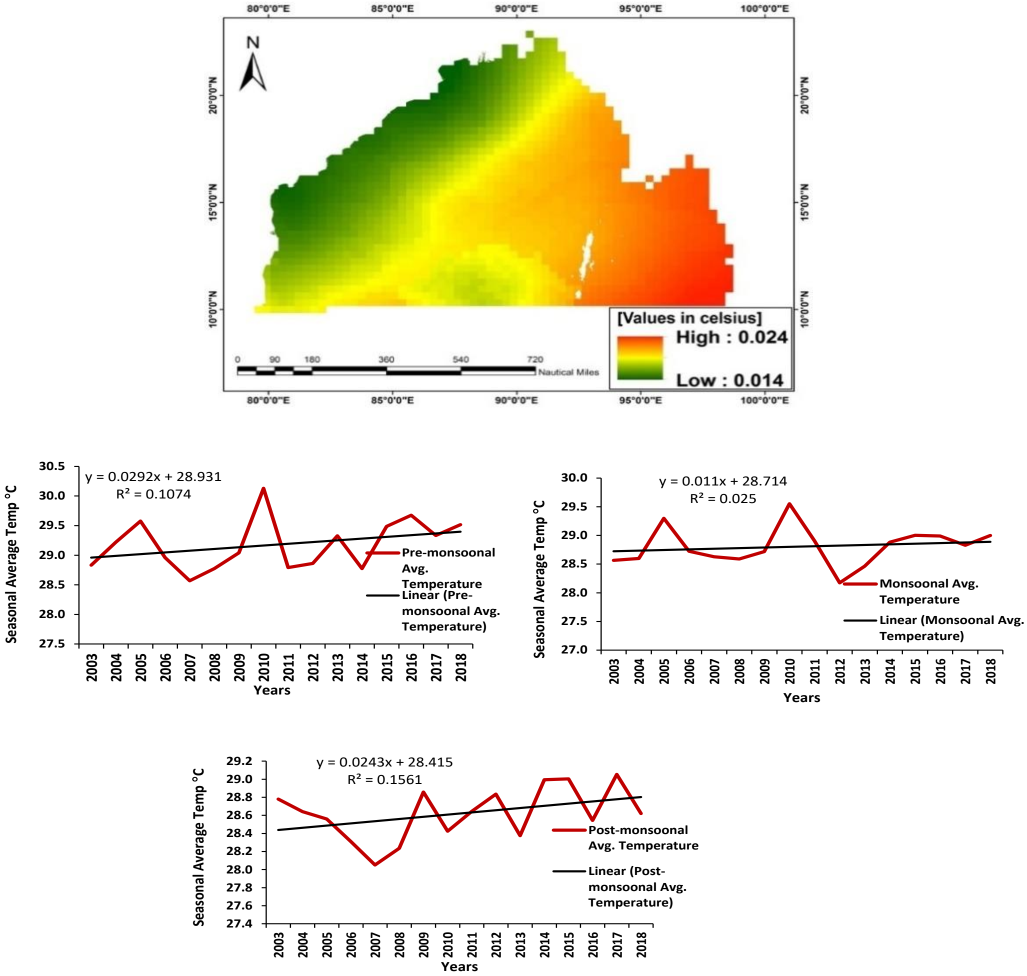


Fig 4.6.1 Seasonal SST trend analysis in Northern part of Bay of Bengal for the period 2003-2018.

4.6.2 Sea level rise

The ocean level has increased by approximately 20 to 25 centimetres globally over the past century (Pittock, 1999; Church and White, 2006). Current forecasts indicate that sea levels could rise between 0.98 to 1.88 meters under the SSP5-8.5 scenario by the year 2150 (IPCC Climate Change Report, 2023). There is growing apprehension that if both the Greenland and West Antarctic Ice Sheets are to fully melt, global sea levels could surge by over 10 meters compared to current levels (IPCC Climate Change Report, 2001). Research has demonstrated that sea levels have been rising at 5 mm/year rate in deltaic region of Ganga, Brahmaputra andMeghna, (Antony et al., 2016; Unnikrishnan and Shankar, 2007). Sea level escalation takes place at a slower pace compared to growth of corals (Done, 1999). However, it's important to note that sea levels could rise significantly above coral growth, stabilizing at 6 to 10 meters above the current sea level if ice sheets in polar sub polar region melt very fast (Overpeck et al.,2006)

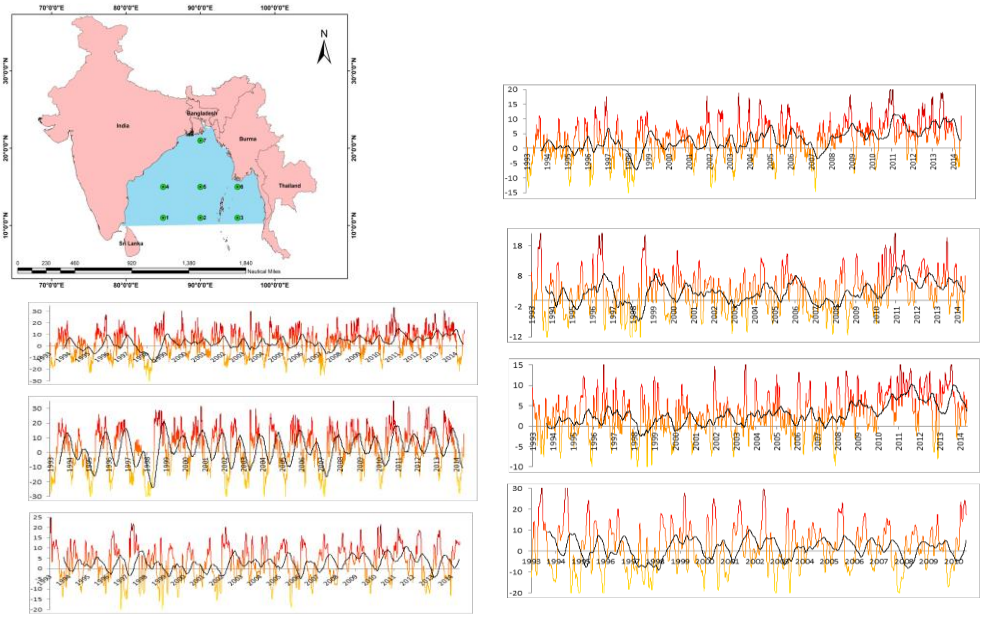


Fig 4.6.2 Sea surface height anomaly studied in the Northern part of the Bay of Bengal

4.6.3 Identification of Vulnerable Coral Sites

The Coral Vulnerability Index scores were meticulously utilized to categorize each tehsil in Andaman into five distinct vulnerability classifications (Table 4.6.3). This process facilitated the creation of a comprehensive vulnerability map in ArcGIS 10.5, achieved through the adept application of classification techniques.

The in-depth analysis identified Diglipur and Mayabunder as the most susceptible areas, with very high and high vulnerability rankings respectively. Conversely, Ferrargunj exhibited a moderate level of vulnerability. Rangat and Port Blair were highlighted as areas with low and very low vulnerability, attributed to the presence of crucial protective features like Marine Protected Areas and coastal mangrove swamps. A comprehensive multi-hazard assessment revealed that

Mayabunder and Diglipur faced the highest risk of climate threats, while Rangat and Port Blair followed closely. In contrast, Ferrargunj exhibited minimal exposure to environmental threats (Fig 4.6.3).

Table 4.6.3 Results of different variables after Min-Max Rescaling and final coral reef vulnerability calculation

Contributing Factors	Variables	Diglipur	Mayabunder	Rangat	Port Blair	Ferrargunj
Exposure	Pre-Monsoon Rainfall	0.12	0.21	0.28	0.71	0.80
	Monsoon Rainfall	0.87	0.63	0.30	0.13	0.17
	Post Monsoon Rainfall	0.85	0.96	0.52	0.58	0.49
	Current Speed	0.65	0.67	0.83	0.38	0.44
	Sea Surface Temperature	0.44	0.89	0.93	0.39	0.64
	Wind Speed	0.87	0.68	0.44	0.16	0.26
Exposure		0.63	0.67	0.55	0.39	0.47
Sensitivity	Bleaching Intensity	0.00	1.00	0.00	0.67	0.78
	Coral Reduction	1.00	0.45	0.00	0.25	0.04
	Coral At Risk of Inundation	1.00	0.23	0.00	0.02	0.33
	Erosion	0.00	0.00	0.06	0.01	0.33
	Accretion	0.16	0.05	0.03	0.00	0.01
Sensitivity		0.43	0.35	0.02	0.19	0.30
Adaptive Capacity	% Coral Regeneration	0.13	0.00	1.00	0.61	0.05
	Marine Protected Areas	0.50	0.50	1.00	1.00	0.00
	Adaptive Capacity	0.31	0.25	1.00	0.81	0.03
VI		0.139	0.147	-0.005	0.069	-0.160
RANK		4	5	2	3	1

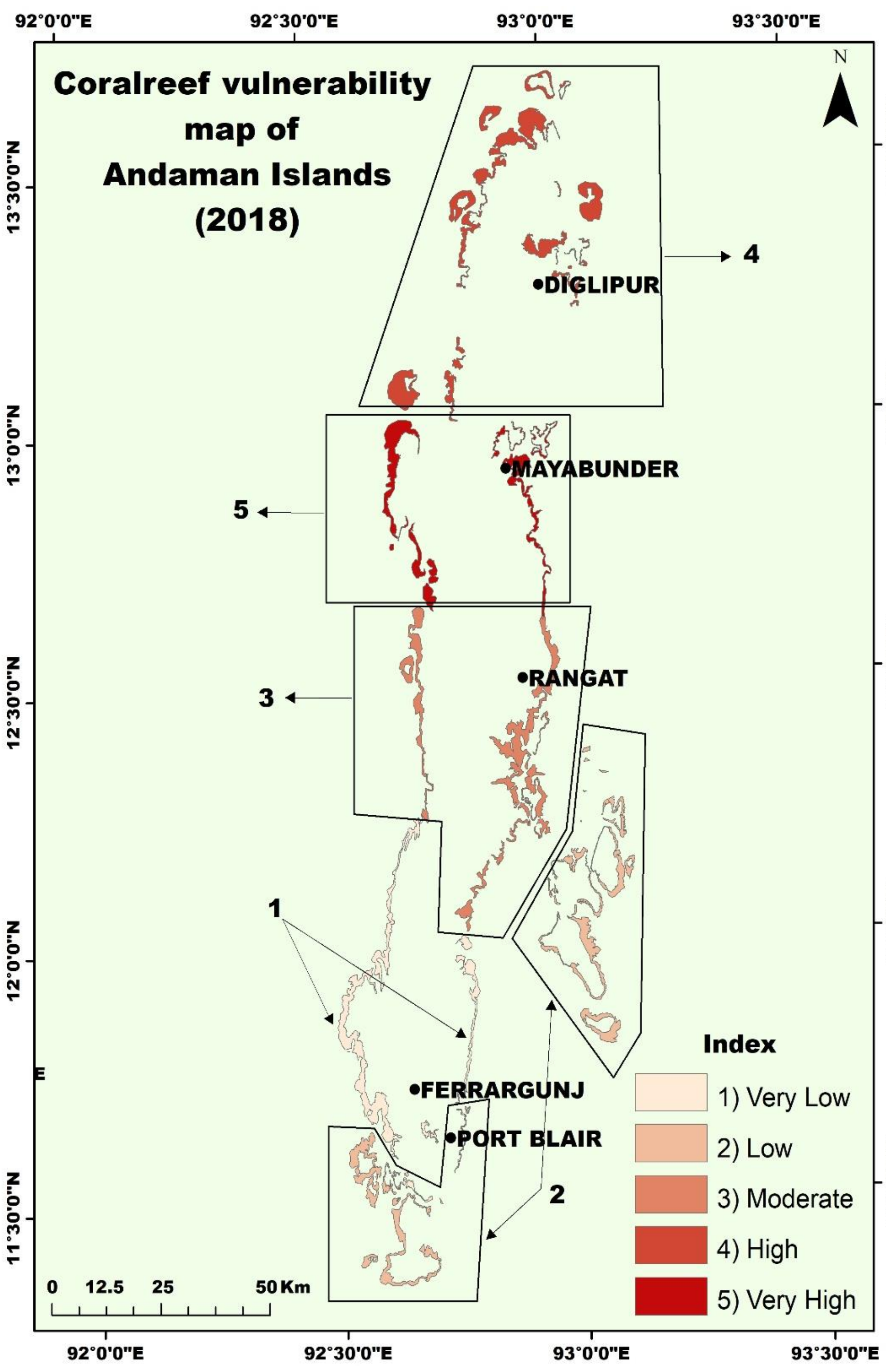


Fig 4.6.3 Coral reef vulnerability ranking of each tehsil of Andaman Islands based on IPCC AR4 framework

4.7 Discussion

4.7.1 Mangrove Vulnerability

In this study, the vulnerability score of mangroves was used as a standard measure to compare different areas in the Andaman region for their long-term endurance. The temporal analysis of the mangrove areas of Rangat, Ferrargunj, and Port Blair revealed a significant reduction in mangrove aerial cover from 1993 to 2018 with maximum replacement of dense mangroves by open mangroves in 2010. The health of the mangroves has also deteriorated notably in Diglipur and Port Blair. Between 1990 and 2000, the forest cover increased due to strict surveillance by the Forest Department of ANI. However, there have been significant deviations in structure and composition of the vegetation after the tsunami, highlighted by dominance of mono plantations (Majumdar et al, 2019). The Bay Island's mangroves are mostly dominated by a single family of Rhizophorecea, which includes five species of Rhizophora and three species of Bruguiera. While the lower species richness can make the mangroves more vulnerable, the high stand basal area, species diversity, and dominance of trees with a diameter greater than 25 sq. meters per hectare indicate a high resilience potential for the mangroves of Andaman. According to Shankar et al. (2020), although the mangrove cover has undergone some spatial changes over the years, the extensive mangrove plantation and lower population pressure in these areas have helped the mangroves thrive well in Andaman.

In North Andaman, less tree density can be attributed to upliftment and the eastward inclination of the landmass due to Tsunami generated earthquake. However, the high tree density in South Andaman could be due to the capacity of mangroves to recolonize in the newly submerged areas (Das et al. 2014). The canopy gap between trees leads to the natural regeneration of tropical mangroves, especially Rhizophoracea which dominates the southern part of the island (Kathiresan and Bingam 2001). In North Andaman the mangroves were found to have a very dense tree canopy which otherwise prevents optimum sunlight from penetrating the ground, resulting in fewer seedlings and saplings and more mature tree strands. Moreover, unprotected open mangroves near the villages and mouth of the creeks may degrade over time due to continuous exploitation by the settlers (Majumdar et al,2019).

The islands are vulnerable to encroachments, resulting in deforestation and loss of forest cover. This poses threats to the diversity of plant life on the islands (Prasad et al.,2010). A study of alteration in land-cover, observed through satellite-derived maps, indicates a loss of around 100 square kilometres of forest cover between 1993 and 2018. The loss of forest cover can be linked to a loss of plant species, although it is difficult to quantify this change as there are no records from earlier decades

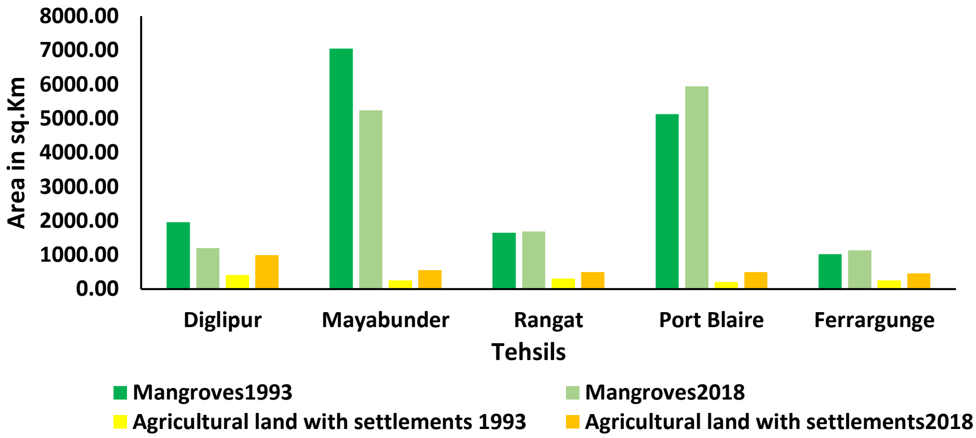


Fig 4.7.1a Temporal changes in mangroves and agriculture with settlement in tehsils of Andaman Islands in the years 1993 and 2018

Additionally, the rapid influx of people to the islands over the past fifty years has led to agricultural expansion (as evident from LULC analysis in Fig 4.7.1a) and other land-use changes, like construction of infrastructure, which has further exacerbated deforestation phenomena (Dey and Chakraborty 1994). The islands are home to a unique array of endemic species, highlighting the importance of preserving their forest cover. Protecting these vital habitats is crucial, as it serves to safeguard the rare and threatened species that rely on them for survival. By focusing on conservation efforts, we can create a more sustainable environment for these distinctive ecosystems. (Prasad et al. 2009).

The study found that the health of mangroves in Rangat was severely compromised, followed by Ferrargunj, while Diglipur and Port Blair showed a comparatively healthy patch. Mangroves in the south and middle parts of the islets are exposed to threats of SLR as compared to their northern counterparts. This is attributed to lesser elevation of South and Middle Andaman Islands (469 metres and 501 metres, respectively) than North, whose maximum elevation is 733 m (Veettil et al, 2020).

About 24% of mangrove habitable area is occupied by mangroves, out of which 17% of the area is below 1 m elevation. This implies that the existing mangrove resources would be significantly affected by future sea level rise scenarios unless they adapt to submerged conditions or extend landward (Krauss et al.,2014).

In December 2004, a tsunami damaged a vast area of mangroves in both North and South Andaman. The depletion of mangroves in North Andaman was mainly due to the fall in sea level, which resulted in the mangroves not receiving tidal waters and gradually wilting (Ramakrishnan et al., 2020; Meltzner et al. 2006). While 95% of the mangrove cover was found to be degraded along the west coast, only 60% were destroyed along the eastern counterpart. The upliftment of the island with a tilt towards the east resulted in the western coast being uplifted more (Meltzner et al. 2006). Such a disposition restricted mangrove growth simply along the creek margins since tidal ingress ceased over considerable portions of the mudflat, thereby reducing the salinity and nutrient availability for the mangrove. Such changes in hydrological conditions led to large-scale mangrove mortality in North Andaman. But in South Andaman land subsidence by one metre damaged the mangroves due to permanent inundation of their roots (Malik et al.,2006) whereas mangroves in middle Andaman remained untouched by Tsunami (Dam Roy and Krishnan 2005). While anthropogenic impact like logging is a more dominant factor for mangrove depletion in North Andaman natural causes like Tsunami and sea level rise are the chief stress factors for mangrove depletion in Mayabunder, Corbyn's Cove, Wright Myo, Shoal Bay and Sippighat (Saxena et al,2013; Veettil et al.,2020). From LULC analysis, conducted in the present study it could be found that in 2010 mangroves and corals exhibited loss of approximately 84 square kms and 73 square kms respectively since 1993 (Fig 4.7.1b)

The flood inundation risk map revealed that only 12.8 and 4 square kilometres of area of North Andaman tehsils like Diglipur and Mayabunder were at risk of flooding whereas Port Blair and Ferrargunj account for 13.14 and 6.40 square kilometres of flooding zones. In terms of the percentage of mangrove inundation Rangat spearheaded while Diglipur had the lowest share of mangroves in high-risk inundation zones of 2-4 m elevation (Table 4.7.1).

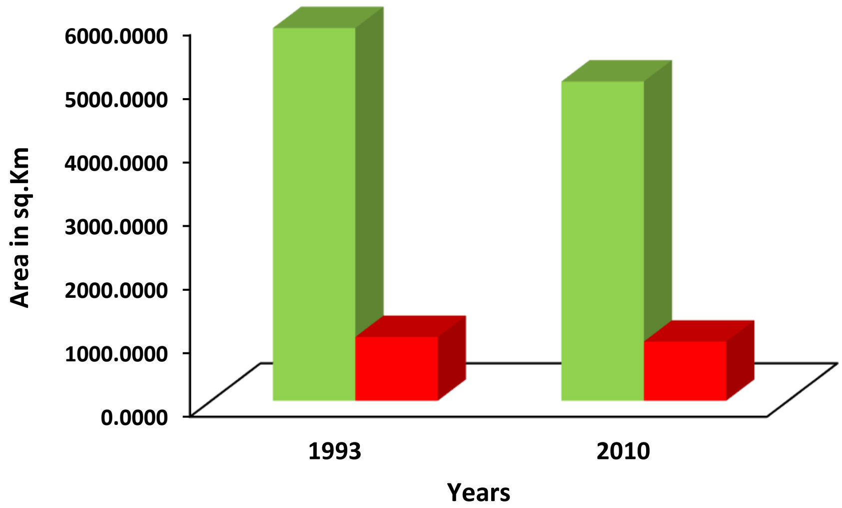


Fig 4.7.1b Pre and Post Tsunami assessment of mangroves and reef cover of Andaman Islands.

Table 4.7.1 Tehsil wise distribution of percentage share of mangroves and coral reefs at risk of inundation during wave run up of 2-4 m

Tehsil	Total inundation area in sq.km	% of Mangroves inundated	% of Corals inundated
Diglipur	12.80	11.60	33.65
Mayabunder	4.17	16.58	22.91
Rangat	10.76	30.82	19.74
Port Blaire	13.14	21.83	19.95
Ferrargunj	6.40	17.87	24.32

A large portion of mangroves of Middle Andaman Island are at risk of flooding due to its headlands extending into the sea, making it vulnerable to rising sea levels. Backwater streams cutting inward towards the land in the southeast pose a threat to the mangrove tracts and the villages of Bakultala and Rangat. Despite the higher elevations observed in the western edges of this area, certain parts are still under threat because of the effect of bathymetry, which causes change in the direction of tsunami waves, resulting in higher wave run-ups (Prerna et al.,2015). Owing to higher regional elevation, threats of future flood inundation as well as risk of flooding of mangrove zones or reefs due to wave run-up are comparatively low in tehsils of South Andaman- Ferrargunj and Port Blair (Fig 4.7.1c).

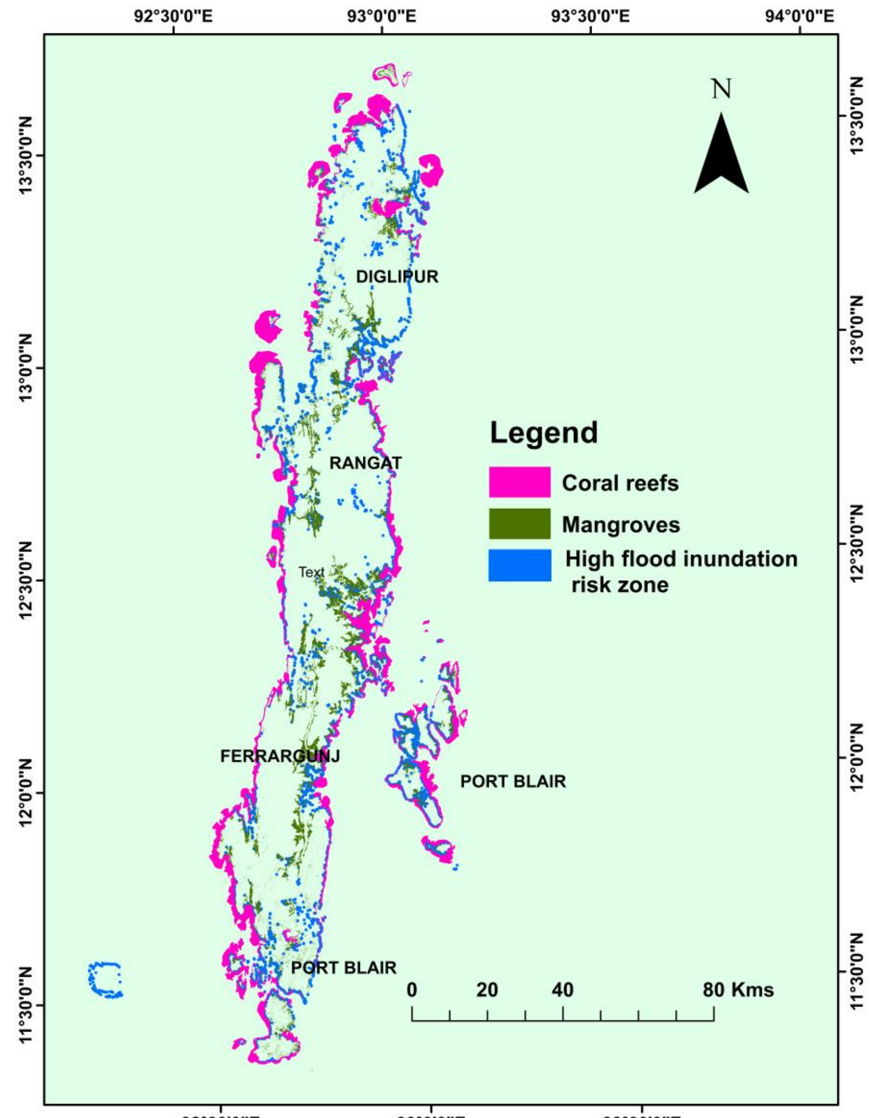


Fig 4.7.1c. Inundation risk of mangroves and coral reefs at wave run up height of 2-4 m

The risk profile of Diglipur, Mayabunder, and Rangat tehsil is moderate to very high due to various factors. These include the reduction of mangrove and coral ecosystems during the 2004 tsunamis, the infringement of forest lands for refugee rehabilitation over the past five decades along with agricultural expansion, a continuous decrease in precipitation, and the impact of global climate change. However, the Rangat region is in a comparatively better state as the tidal flux flows a long distance in these creeks after the tsunami, which helps in the steady change of the landscape into mangrove forests (Chakraborty et al.,2021). The concentration of low to very-low high-risk zones is spread over the southern and southwestern part of the region, which is influenced by enriched sediment built-up, recolonization ability of tree species and good government initiatives compared to the rest of the region (Chakraborty et al.,2021)

4.7.2 Coral Vulnerability

Table 4.7.2, represent mass bleaching evets witnessed by the island. In 2005, there was a 7.5% patchy bleaching recorded in North Bay during April and May. The bleaching lasted from April to June, about four months after the tsunami. A gradual recovery of about 4.7% was observed, while 2.8% of the bleached coral failed to recover (Krishnan et al., 2011). The temporary bleaching observed in North Bay in 2005 suggests that this phenomenon may be due to the expulsion of depth and low-light intolerant zooxanthellae, which are replaced by low-light and depth tolerant ones. This can be seen as an adaptive strategy of the coral to maintain the balance of the symbiosis and zooxanthella diversity (Dharani et al., 2012). Additionally, between 37% and 70% of corals in various locations experienced extensive bleaching in April and May 2010. This occurred when the weekly sea surface temperature (SST) fluctuated between 31.0°C to 33.0°C from last weeks of April to first week of May (Krishnan et al., 2011) (Fig 4.7.2).

On December 26, 2004, a major earthquake struck approximately 30 km beneath the earth's crust near Sumatra in the Indian Ocean. The rupture along a 1200 km fault line triggered a series of secondary earthquakes as it moved north through the Andaman and Nicobar Islands. This geological event unleashed a devastating tsunami, solidifying its status as one of the deadliest disasters in modern history (Jeyabaskaran et al., 2007; Kulkarni et al., 2008).

The North Andaman experienced an uplift of 0.60–0.90 cm, causing a noticeable decrease in water levels (Jeyabaskaran et al., 2007). In the South Andaman region (including Colinpur and Chidiyatapu), coastal subsidence of less than 1 meter resulted in reduced reef areas and the death of mangrove habitats. The destruction of coral reefs was primarily confined to shallow waters (up to 5 meters deep) in the region. The uplift of North and Middle Andaman led to the demise of shallow coral reefs due to prolonged exposure. Additionally, a 1.1-meter increase in water column height resulting from land subsidence forced shallow-water corals into deeper environments (Kulkarni et al., 2008

Table 4.7.2 Mass bleaching events witnessed by various reefs of Andaman Islands

Year	Month	SST (℃)	Place affected	Extent of bleaching	Reference
1998	May	31.27 °C	Ross island, North Bay, Marina Park	85% partially bleached	Ravindran et al. (1999)
2002	April-May	31.6 °C to 32.2 °C in the last three weeks of April to 31.3 °C - 31.9 °C during the first week of May.	South Button Island, Havelock Island, NorthBay, Chidiyatapu, Redskin Island, Nicolson Island	20 - 40%	Krishnan et al. (2011)
2005	April-May	weekly SST ranged from 30.8 °C - 32.2 °C and 29.8 -31.1°C during the first week of May	South Button Island, Havelock Island, North Bay, Chidiyatapu, Redskin Island, Nicolson Island	20 - 40%	Krishnan et al. (2011); Sarkar et al. (2013)
2010	1. April-May	Weekly SST in the last two weeks of April was 31–32°C and increased to 33°C in the first week of May	South Button Island, Havelock Island, North Bay, Chidiyatapu, Redskin Island Nicolson Island Ross Island	37 - 70%	Mondal et al. (2014)
	2. May	31.7 °C	Mayabunder, Rutland Island, Rani Jhansi Marine National Park, Mahatma Gandhi Marine National Park	69.43 - 90.43%	Marimuthu et al. (2013)
	3. April-May	30.5 °C to 34 ℃	Within the Bays Of Port Blair.	74 -77%	Mohanty et al. (2017)
2016	19th April-26th April, 2016	31.8 °C to 32.30 °C	North Bay near Port Blair	Some species of *Acropora* and *Fungiid*	Mohanty et al. (2017)

This sudden change in habitat could have caused photo limitation or pressure stress, potentially facilitating the expulsion of zooxanthellae from the coral or the symbiotic algae (Krishnan et al., 2011).

The mega earthquakes and subsequent tsunami had devastating effects on coral reefs through displacement and uplift (or subsidence) of the coastal segments, dislodging and smashing of corals and smothering of corals by sediment load driven from land (Jeyabaskaran, 2007). Initial live coral cover averaged 73.5%, with Acropora sp.

dominating at 31.7%, followed by Porites sp. at 21.8% and Millepora sp. at 10.7%. However, by 2006, abundance of branching corals drastically reduced to 8% and 2%, respectively (Narayana, 2011). This mortality was due to sediments being mobilized by wave action and currents, leading to the smothering of corals (Majumdar et al.,2018) Fig 4.6.1b. shows significant loss of mangroves and coral reefs in Andaman Island post Tsunami through LULC analysis over the time frame 1993 to 2010.

By collecting data on bleaching intensity and area of damaged reefs after the Tsunami from various literature and feeding the same in the vulnerability model, the sensitivity of corals to such threats was analysed. Further inundation (Table 4.6.1c) scenarios were also taken into account for sensitivity analysis and it was found that Diglipur and Ferrargunj exhibited the highest sensitivity followed by Mayabunder whereas Port Blair had the lowest sensitivity to such threats (Fig 4.6.1c)

The Andaman region receives around 300 cm of rainfall each year (Raghuraman et al., 2012). Several reefs in the Port Blair area are facing a threat from siltation due to increased discharge of rainfall in semi-enclosed bays and lagoons as runoff, and deposition of large amounts of sediments and nutrients (Raghuraman et al., 2012). In May 1989, corals at Wandoor Marine Park area, Port Blair, and Labyrinthine Island in South Andaman, succumbed to widespread siltation (Pillai, 1996).

The storms with moderate disturbances, can help maintain species richness by thwarting any one foremost species from taking over (Connell, 1978; Connell et al.,1997). However, intense cyclones, could cause stress to the reefs beyond what they have previously experienced. Coastal coral communities may be especially vulnerable to more frequent and powerful cyclones. This is because the runoff from the land and resuspension of sediment will increase with these stronger cyclones (Mumby et al., 2001; Hughes et al., 2003). In coastal areas, hurricanes result in heavy downpour while destructive wind forces occur over tens of kilometres (Furnas, 2003). Major flooding events, caused by freshwater runoff and dissolved nutrients from coastal catchments, pose a significant threat to corals in nearshore waters (Burrage et al., 2002; Devlin and Brodie, 2005; Larcombe et al.,1995; Anthony and Connolly 2004).

The occurrence of severe cyclones has nearly doubled over the last thirty years across all ocean basins (Webster et al., 2006; Emanuel 2005). In the Bay of Bengal, tropical cyclones tend to be more frequent during the summer months from April to

June, and from October till December (McPhaden et al., 2009; Girishkumar and Ravichandran 2012; Sahoo and Bhaskaran 2016). The development of tropical cyclones is strongly supported during these months by consistently warm sea surface temperatures (SST), a thermodynamically unstable atmosphere, and low tropospheric wind shear (McPhaden et al., 2009; Girishkumar and Ravichandran 2012).

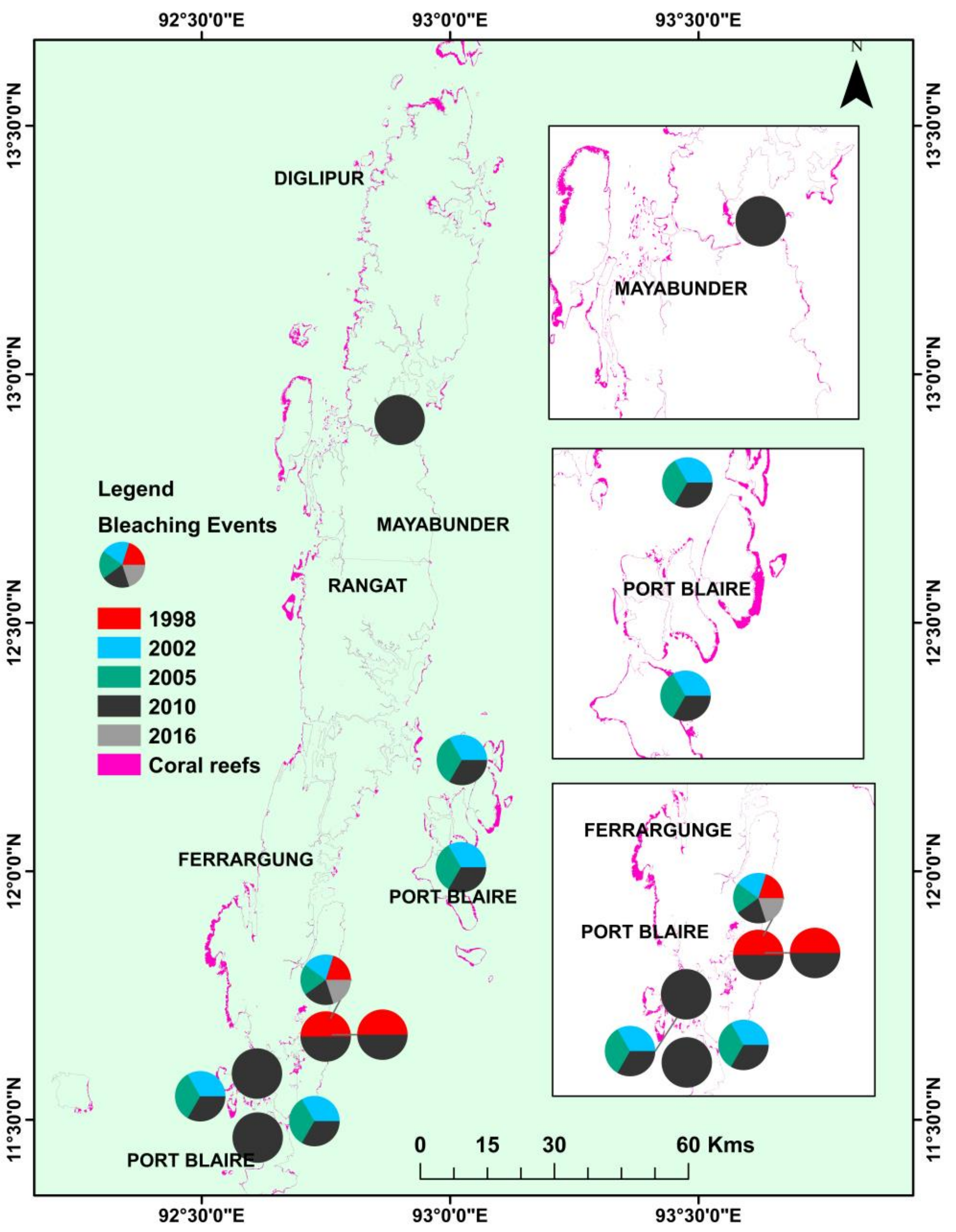


Fig 4.7.2 Bleaching episodes witnessed by reefs of Andaman Islands

4.8 Adaptive Management

Mangroves are generally able to withstand natural disturbances and can successfully start growing again within 15-30 years under favourable conditions (Bhatt and Kathiresan 2012). Recent studies have shown a rise in mangrove forest area, particularly in newly formed intertidal areas of South Andaman (Sachithanandam et al. 2014). This suggests that new mangrove vegetation could be recruited from nearby areas that have not been affected (Das et al.2014). In a recent study, Shivashakar et al (2020) identified eight new sites of mangrove colonization spread over Ferrargunj and Port Blair where the dominant species is Rhizophora spp. Following tectonic subsidence induced by the Tsunami, new geomorphology, fresh water, soil and nutrients provided by tropical rains, new mudflats created an environment that allowed mangroves to colonize in South Andaman, (Shivashankar et al., 2020) as evidenced in the present study (Fig 4.8a.).

Adaptability of corals to changing environment, is a fascinating topic of study (Brown et al., 1996; Coles and Brown, 2003; Gates and Edmunds, 1999). Several instances of coral hosting multiple genetic varieties of Symbiodinium suggest that environmental conditions can cause a shift in dominance from one genetic variety to another (Baker, 2001; Berkelmans and van Oppen 2006). For example, in order to increase their thermal tolerance branching corals like Acropora with multiple genetic varies have freedom to change their symbiont. A promising avenue for corals to acclimate is the potential switch to a more thermally tolerant symbiote, as Buddemeier and Fautin (1993) proposed in their Adaptive Bleaching Hypothesis.

Although corals having high growth rates are capable of keeping up with projected sea-level rises regrettably, ongoing ocean warming, accompanied by acidification and widespread bleaching episodes diminish calcification rates, thereby feasibility of corals in Andaman Islands just like Great Barrier Reefs of Australia (Hoegh Guldberg O et al.,2007).

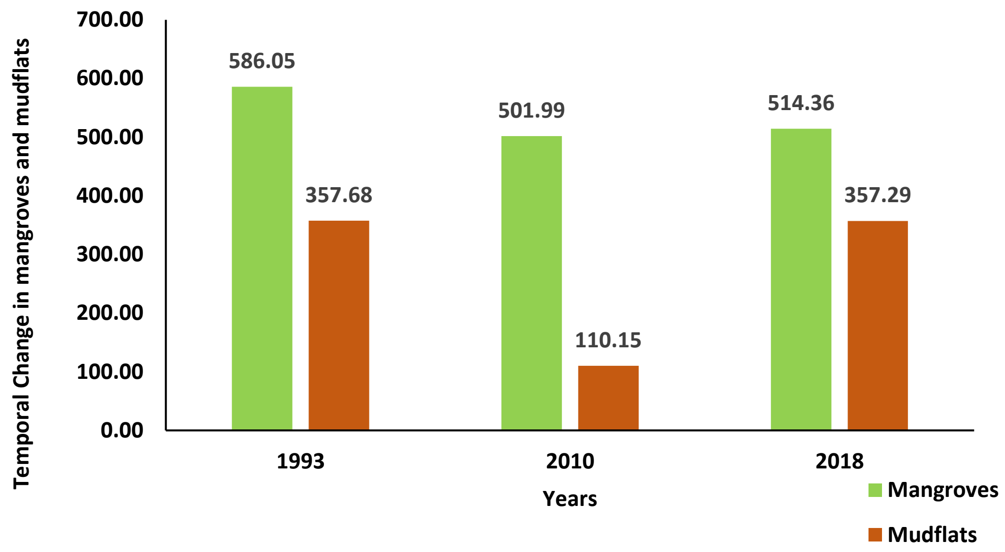


Fig 4.8a. Regeneration of mangroves and mudflats over the years 1993,2010 and 2018 reflecting adaptivity of mangroves to climate extremes

Indian Ocean experienced significant coral recovery after the mass bleaching event in 1998 (Baker et al., 2008). According to Marimuthu et al. (2013),74% corals in Havelock Island were bleached in July 2010. By January 2011, approximately 13.29% of the corals had recovered. The massive forms of coral, experienced the fastest recovery. On the other hand, the branching forms like Acropora were severely damaged by the impact. In Port Blair Bay, although 77% of corals bleached in July 2010, 21.1% showed signs of recovery by January 2011 (Marimuthu et al., 2013). Favourable conditions following the onset of rain in June 2010 allowed fastest recovery of bleached corals. In June 2010, 87% of corals in South Andaman were bleached, with a subsequent recovery rate of 13%–21% (Mondal et al., 2014). Following the 2010 bleaching event, post-tsunami islands showed estimates of new colony recruitment and coral regrowth, with coral density ranging from 14 to 22 colonies/10m2 in Rutland Island of South Andaman (Turner et al., 2009).

Creating a Marine Protected Area is an effective method for protecting the biodiversity. However, it's important to remember that MPAs won't necessarily address larger issues like climate change and coral disease outbreaks (Selig and Bruno, 2010).

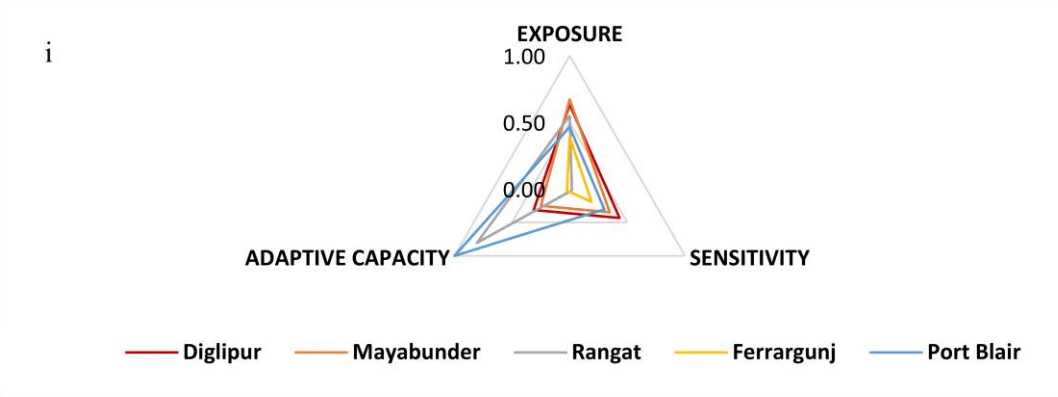
India has established a network of protected areas guard ecologically important areas. Over time, the number of MPAs has increased to encompass critical marine ecosystems. Currently, the majority of coral reefs and mangroves in the country are part of the MPAs.

The Andaman and Nicobar Islands have 105 protected areas, with 15 classified as Marine Protected Areas (MPAs). MPAs are primarily marine environments or areas that significantly affect the marine ecosystem (Singh,2003). The literature on Marine Protected Area (MPA) governance highlights a significant issue of applying land-based management strategies to marine environments. Unlike terrestrial areas, marine spaces are dynamic, with higher ecosystem complexity, diversity, and vulnerability. Consequently, governance systems designed for land may not effectively manage marine spaces. Despite this, the Indian Forest Department's focus on terrestrial conservation is reflected in its approach to managing Protected Areas (PAs) in the Andaman Islands (Bijoor et al.,2018).

Recently, scientists have reached a consensus that simply protecting isolated coral reefs does not effectively prevent their squalor. They suggest working together at a large scale to strengthen the entire coral reef system against different challenges. (Harvey et al., 2018; McCook et al., 2010;). Human-assisted evolution represents an innovative management strategy for coral reef ecosystems. This approach involves the transplantation of genetically modified corals that exhibit increased tolerance to environmental stressors (van Oppen et al.,2015). Such modifications can enhance the resilience of coral organisms against challenges such as rising temperatures and ocean acidification, as well as improve their ability to recover from ecological disturbances. This method holds significant potential for promoting the long-term sustainability of coral reefs (Athony,2015).

Based on Hahn et al. (2009), vulnerability triangles were created for mangroves and corals, on the basis of mean ranks of the vulnerability components (Fig 4.8b i and ii). Mayabunder and Diglipur's mangroves and corals are most exposed to climate change impacts, closely followed by Rangat and Ferrargunj. Port Blair, however, has the lowest exposure. Ferrargunj's mangroves show the highest adaptive capacity components compared to the other sites, while the dominance of marine protected areas and faster coral regeneration determine the higher adaptive capacity of Port Blair and

Rangat. In contrast, Mayabunder's mangroves and Ferrargunj's corals rank lowest in terms of adaptive capacity components. Mayabunder leads to vulnerability among the tehsils due to its highest sensitivity components. Components of vulnerability that are ranked higher than others can be targeted specifically for management decisions. This approach can lessen any identified vulnerability in the components that have higher ranks.



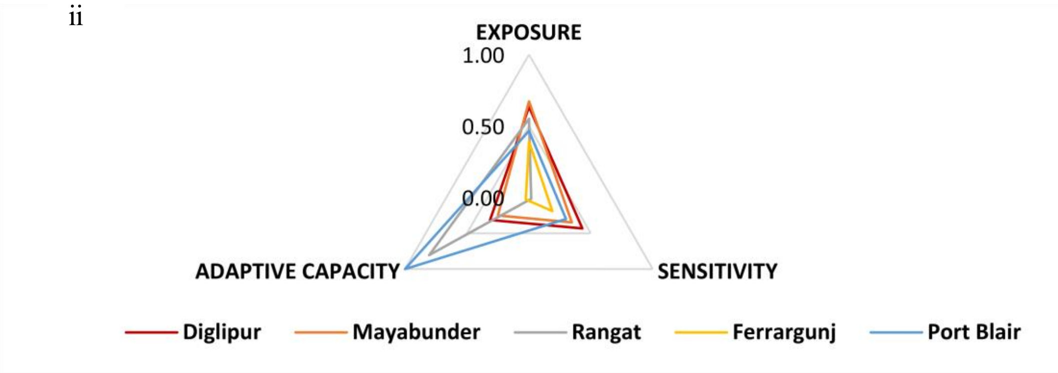


Fig 4.8b Vulnerability Triangle of i. mangroves and ii. corals based on exposure sensitivity and adaptive capacity

4.9 Conclusion

This paper has attempted to portray a detailed scenario of possible impacts of natural stressors as well as human pressure on mangrove species of Andaman Island. Mayabunder ranked with very high vulnerability followed by Diglipur. Sufficient regeneration of new mangroves, along with build-up of new mudflats portrayed high adaptation skills of mangroves in various parts of Ferrargunj and Port Blair regions.

The validated techniques from this multidisciplinary approach to vulnerability assessment were based on the study by Ellison (2015). These ranking methods enable policy-makers to judge the integrity of stressed ecosystems and offer early warning systems for environmental changes, ensuring that the mangrove system remains within safe limits regarding exposure to stressors. Such assessments should account for varying management possibilities and institutional changes.

CHAPTER-5

INTEGRATED SOCIAL VULNERABILITY ASSESSMENT OF POPULATION OF ANDAMAN ISLAND

5.1 Introduction

Climate change, manifested through climate variability and extreme weather events, has clear direct and indirect effects on the environment, biodiversity, and socioeconomic areas, including water and agricultural resources, food security, and human health (UNFCCC, 2007; Field et al., 2014). Globally, agricultural production is profoundly influenced by rising temperatures, erratic rainfall patterns, and extreme phenomena such as droughts and floods (FAO, 2016; Fields, 2005; Hahn et al., 2009). Moreover, ocean acidification, alterations in ocean temperature and levels of the ocean, and their related ecological shifts have negatively impacted coastal livelihoods (FAO, 2016; Shelton, 2014). Projections suggest that extreme heatwaves will become more common in Asia, with a significant portion of South Asia anticipated to face severe temperatures near future (high confidence). The rise in temperatures will also result in higher moisture convergence and increased monsoon precipitation across East, Southeast, and South Asia (Doblas-Reyes et al., 2021).

The consequences of global climate events have significant social repercussions, posing threats to human health and well-being, depleting coping strategies, and notably increasing the number of individuals and communities that are threatened (Ford et al., 2015; Sovacool et al., 2017). Increasing number of people in under-developed regions are more exposed to climate change with minimal means to adapt, and vice versa (Auffhammer and Kahn, 2018). Residents living in climate change hotspot areas of South Asia, are threatened by recurring floods and drought which further affect their agriculture-based economies (Ahmad, 2015; Kirby et al., 2016).

The conventional approach to climate change studies has focused solely on projecting climate variability using models. However, these studies have glaringly failed to consider the various social indicators that also significantly contribute to population vulnerability (Houghton, 2009). It is imperative to recognize that climate change is undeniably intertwined with the social aspects of vulnerability. Consequently, the field of vulnerability studies must urgently evolve into a new research paradigm of society-nature relationships, in which human beings proactively fight against various natural perils (Vincent, 2004; Teshome, 2015; Kelly & Adger, 2000)

5.2 Social Vulnerability and its Indicators

The susceptibility of communities to natural adversities exacerbated by climate change is influenced by their proximity to potential hazards, but also by their social status (Cannon 1994). There is a growing consensus among researchers that in addition to physical meteorological factors, social, economic, and built environment aspects can effectively mitigate the hazards of climate change (White and Howe, 2010). Flanagan BE (2011) identified various domains of social vulnerability factors:

(i) Demographic: Demographic characteristics such as age, gender, household composition, are studied in conjunction with financial features to assess socio-economic status of the unit (Tierney K,2006)

(ii) Socioeconomic: When analyzing social vulnerability domains of education, job availability, poverty, income strength are considered (Flanagan BE,2011).

(iii) Housing and Infrastructure: Indicators such as electricity, and water supply, road networks or public transportation are considered in this category (Zandt S Van et al,2012; Waly et al,2021).

The emerging cohesive vulnerability framework has arisen due to the shortcomings of existing biophysical and socioeconomic vulnerability frameworks (Fussel & Klein, 2005; Houghton, 2009). The impact of natural elements on people is significant, so it's important to consider the socio-economic context when evaluating it (Luk, 2011). The study utilized an integrated vulnerability framework approach, which evaluates vulnerability by considering climatic elements to gauge the community's exposure to climate variations (Fussel & Klein, 2005).

5.3 Social Vulnerability Assessment in Andaman Island

The coastal regions of the Andaman are encountering serious challenges from both natural and human-related causes as discussed earlier in previous chapters. Table 5.3 shows a detailed layout of different socio-economic variables taken for the present study compiled from Census of India 2011.

Table 5.3 List of socio-economic variables selected for Social Vulnerability assessment

Socio economic variables	Diglipur	Mayabunder	Rangat	Port Blair	Ferrargunj
No. of Households	10702	6316	9181	41473	12498
Average household size	4	4	3.9	3.9	4.3
Total population	43183	25788	36626	165754	53565
Area in sq.km	1523.37966	857.4217717	1355.34786	548.4115	1343.697761
Population Density	28	30	27	302	40
Urban population	0	0	2741	132785	7962
Rural population	43183	25788	33885	32969	45603
Female Population	20584	12459	17693	76343	25657
ST Population	125	189	444	2104	489
Child Population	5174	2988	3666	10699	5854
Illiterate Population	11924	6178	8812	31287	11682
Total workers	16,384	9237	12958	44006	20558
Marginal workers	3374	1922	2245	3019	4241
Non workers	26799	16551	23668	64052	33007
Agricultural dependents	7019	3133	2490	350	3513
% of Kutchcha house	17.3	18.1	10.4	2.1	2.4
% of ownership status	44.9	37.4	38.3	53.5	28.9
Unsafe drinking water	23.3	10.7	6.8	1.8	4.1
No electricity	39.4	28.7	16.5	4.2	15.2
No sanitation	53.9	53.8	47.9	16.1	35.9
Education facilities	70.83	68.09	49.37	76.67	62.9
Medical facilities	38.89	51.06	24.05	46.67	41.94
Transport and communications services	80.56	53.19	58.23	86.67	82.26
Approach by Pucca road	45.83	53.19	49.37	76.67	83.87
Households with assets	159	169.1	201.4	265	208.2

5.4 Methodology

Similar to the biophysical vulnerability assessment of mangroves and coral ecosystems of Andaman, the methodology of this study is based on the IPCC AR4 working definitions. The vulnerability index has been constructed at the tehsil level using the Min-max rescaling transformation. The details of the index and the estimation of various parameters have been discussed in Chapter 2, Section 2.6.1-2.6.3

5.5 Results

The variables such as temperatures, precipitation, coastal erosion, agricultural dependency, sanitation, literacy rate, personal assets, exhibited significantly higher positive relationships. In contrast, ownership of house or land have displayed negative correlation. Min-Max standardization technique was used to estimate and map the index values of integrated social vulnerability for all the tehsils of Andaman Island to examine the spatial dimension (Table 5.5). The most vulnerable tehsils are Mayabunder followed by Diglipur and, Rangat while Port Blair and Ferrargung are the least vulnerable (Fig 5.5). Climatic hazards data analysis (flood inundation risk, cyclone, and coastal erosion) indicate- tehsils like Diglipur, Mayabunder, and Port Blair are at high risk. The economic vulnerability of the inhabitants has further increased the magnitude of risk in these regions. Overdependence on natural resources, and primitive and unsustainable economic activity, combined with existing local poverty, exacerbate the prevailing vulnerability of this island. The poor economic conditions of a region are generally indicated by a higher percentage of the rural population, agricultural dependency, lack of electricity connection, absence of home ownership, kutcha housing, and unsafe drinking water. It can be observed that Port Blair, with its high percentage of educational and medical facilities, as well as a better transportation system, has more coping mechanisms to combat climate change-mediated stresses compared to other tehsils. These areas are more exposed to environmental hazards and are less equipped with basic services like electricity or road networks.

Table 5.5 Results of different variables after Min-Max Rescaling and final SVI calculations

Contributing Factors	Variables	Diglipur	Mayabunder	Rangat	Port Blair	Ferrargunj
Exposure	Erosion	0.001	0.001	0.064	0.007	0.333
	Accretion	0.158	0.054	0.030	0.001	0.015
	Wind Speed	0.866	0.677	0.445	0.162	0.256
	% Of Inundation Risk	0.744	1.000	0.456	0.974	0.000
	Temperature	0.057	0.155	0.399	0.793	0.686
	Pre-Monsoon-Rainfall	0.124	0.210	0.284	0.705	0.801
	Monsoon Rainfall	0.868	0.634	0.300	0.134	0.167
	Post Monsoon Rainfall	0.855	0.956	0.517	0.582	0.491
	Exposure	0.459	0.461	0.312	0.420	0.344
Sensitivity	Average Household Size	0.500	0.500	0.333	0.333	1.000
	Population Density	0.000	0.007	0.000	1.000	0.044
	% Of Rural Population	1.000	1.000	0.907	0.000	0.814
	% Of Female Population	0.712	1.006	1.003	0.000	0.818
	% Of St Population	0.000	0.460	0.932	0.993	0.696
	% Of Child Population	0.997	0.925	0.638	0.000	0.805
	% Of Illiterate Population	1.001	0.581	0.593	0.000	0.334
	% Of Marginal Workers	0.985	1.001	0.750	-0.003	0.988
	% Of non-Workers	0.902	0.984	1.001	0.002	0.885
	% Of Agricultural Dependents	1.001	0.789	0.438	0.000	0.388
	% Of Kutchcha House	0.950	1.000	0.519	0.000	0.019
	% Of Unsafe Drinking Water	1.014	0.420	0.236	0.000	0.108
	% Of No Electricity	1.000	0.696	0.349	0.000	0.313
	% Of No Sanitation	1.000	0.997	0.841	0.000	0.524
	% Of Agriculture Under Inundation Risk	0.20	0.42	0.39	1.00	0.00
	Number Of Villages at Inundation Risk	0.75	0	0	0.5	1
	Sensitivity	0.75	0.67	0.56	0.24	0.55
Adaptive Capacity	Number Of Educational Institutes	0.786	0.690	0.000	1.000	0.496
	Number Of Medical Facilities	0.146	-0.002	-0.187	-0.372	0.072
	Transport And Communication	0.144	-0.842	-0.215	-1.409	-0.065
	Approach By Pucca Road	-0.337	-0.548	0.000	1.000	1.264
	% Of Household Assets	0.000	0.095	0.400	1.000	0.464
	% Of Ownership Status	0.014	0.211	0.382	1.000	0.000
	Adaptive Capacity	0.125	-0.066	0.063	0.370	0.372
Potential Impact		0.345	0.311	0.174	0.1	0188
SVI		0.301	0.331	0.163	0.063	0.118
Rank		4	5	3	1	2

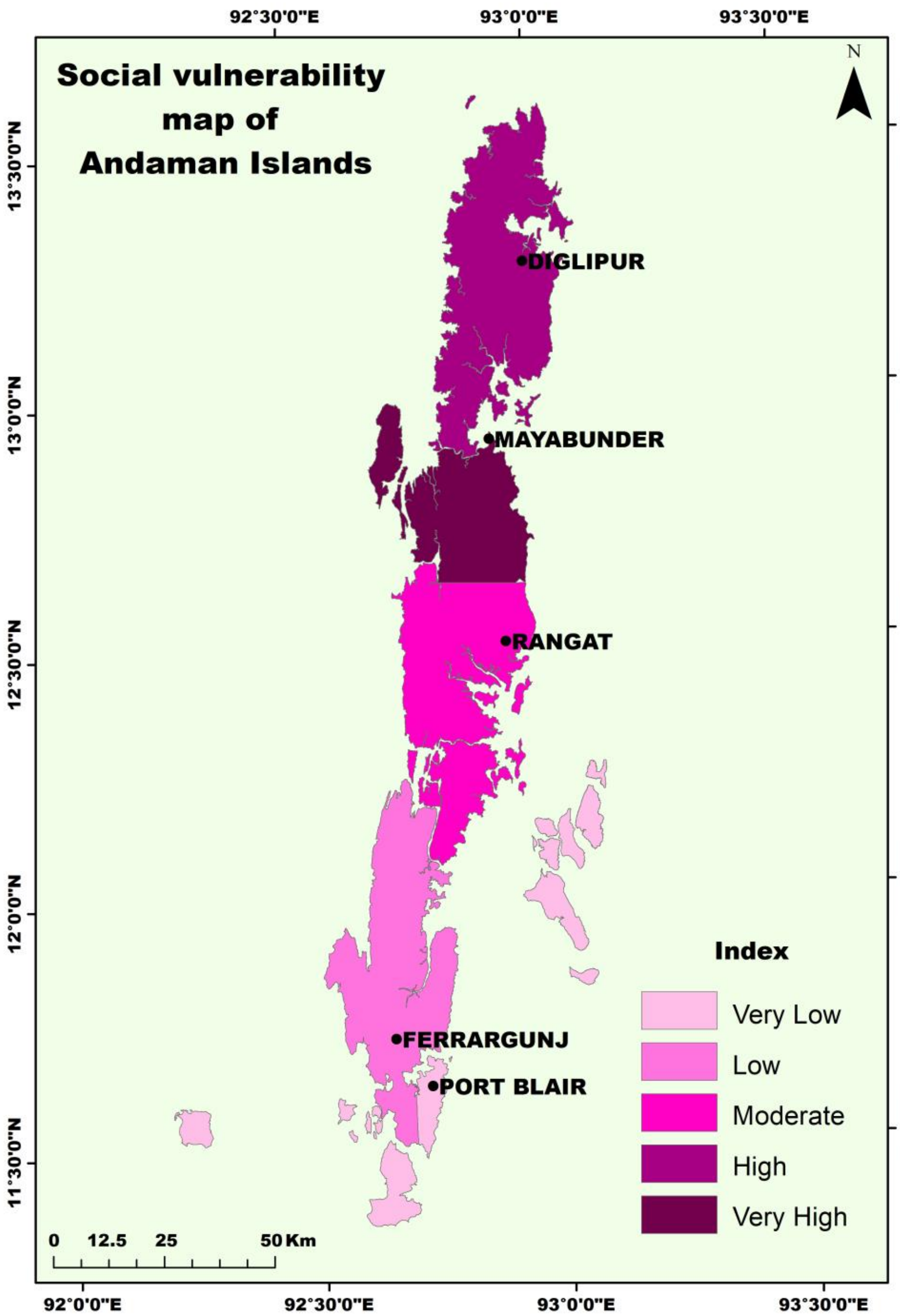


Fig 5.5 Social Vulnerability map of Andaman Island

5.6 Discussion

The vulnerability and risk hotspots for climate change impact, as defined by the IPCC in AR4, were identified at the tehsil level. The framework measured sensitivity of island communities through domains: Livelihood and economic dependency, infrastructure and demographic attributes. The results showed that the communities residing in rural areas with minimal subsistence were the most vulnerable ones. The most vulnerable segment of the population comprised children under the age of 6 and females. While Port Blair exhibited a significant proportion of the female and child population, rural areas were found to be at higher risk when it comes to exposure to disasters. Consequently, Diglipur, with the highest concentration of rural females and children, was identified as the most vulnerable area (Fig 5.6.a).

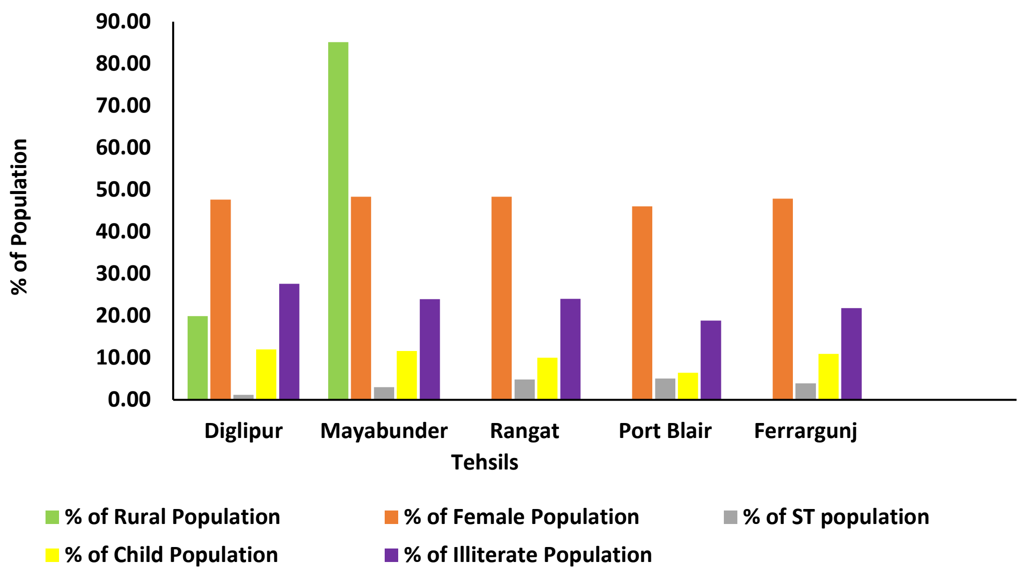


Fig 5.6a. Tehsil-wise distribution of vulnerable category of population in Andaman Islands

According to the AR4 social vulnerability framework, Mayabunder and Diglipur have been identified as the most vulnerable tehsils. Both regions also exhibit significant vulnerability related to mangroves. Various factors contribute to the high scores observed in both social and biophysical rankings of these tehsils. Key among these is the reduction in mangrove and coral coverage resulting from the Tsunami, encroachment on forest areas due to refugee settlements, and agricultural expansion, which have all significantly impacted mangrove ecosystems. Additionally, climatic hazards, the prevailing poor economic conditions among the majority of residents, unsustainable economic practices, and the overutilization of natural resources have further intensified local poverty, exacerbating social vulnerability in the region. Thus, social and physical vulnerability of the region is highly correlated. The tehsils grapple with institutional challenges and increasing biophysical vulnerabilities, positioning them as the most at-risk areas on the island. The people living on the Andaman Islands face numerous challenges due to climate change and inadequate infrastructure. Cyclones, coastal erosion, and frequent flooding often cause serious damage to the islands. Increased degradation of reefs in Junglighat and Panighat has led to higher erosion and wave action along the shore, necessitating the construction of sea walls (Chakraborty et al.,2021). The percentage of formation of cyclonic disturbances is higher in the Andaman Sea, making the islands more vulnerable however due to the smaller shelf width and steeper slopes of the islands, the storm surges never reach the same height as those on the east coasts of the mainland under similar severe storm conditions. (Chakraborty et al.,2021; Kumar et al,2008).

Planning for safety before the cyclone season is crucial and challenging. Evacuation plans and the proximity of cyclone shelters are essential for effective disaster management. People living in kutcha houses or low-lying areas face greater risks (Chakraborty et al.,2021). The study highlighted the potential vulnerability of flooding of villages in Ferrargung, Diglipur and Port Blair, if the wave run-up height ranges from 2 to 4 metres. (Fig 5.6b.). However, the prevalence of Pucca houses in Port Blair indicates better adaptation compared to the other two areas, where the majority live in kutcha houses.

The rapid surge in population resulting from migration and urbanization has significantly impacted the traditional and locally stable ethnoecological system. Indigenous tribes, a crucial component of the system, have preserved the local and regional environment for centuries. The fragile island environment is currently in crisis, and the extreme overutilization of natural resources may lead to irreparable damage (Patnaik,2012). The study showed that Port Blair had the highest population density, with Ferrargunj and Mayabunder following closely with moderate density. As per the Census of 2011, the urban population in Port Blair was 1,35,533 which was,116,198 in 2001. In real terms, Port Blair Town constitutes 74% of the urban population of the entire Union Territories. After gaining independence, the initial wave of people migrating from the mainland included government-sponsored refugees and other designated groups who were settled in the District of Andaman. The town of Port Blair saw a significant influx of voluntary migrants, and this trend continues, although the rate of migration has only slightly decreased recently (Patnaik and Prasad,2005).

Port Blair, being the port of disembarkation, has had to manage the challenges of this population increase. The slight reduction in the growth rate of the urban population in Port Blair can be partly attributed to the sharp increase in real estate costs in the town and surrounding areas during the 1980s (Patnaik,2012). During this time, there was a

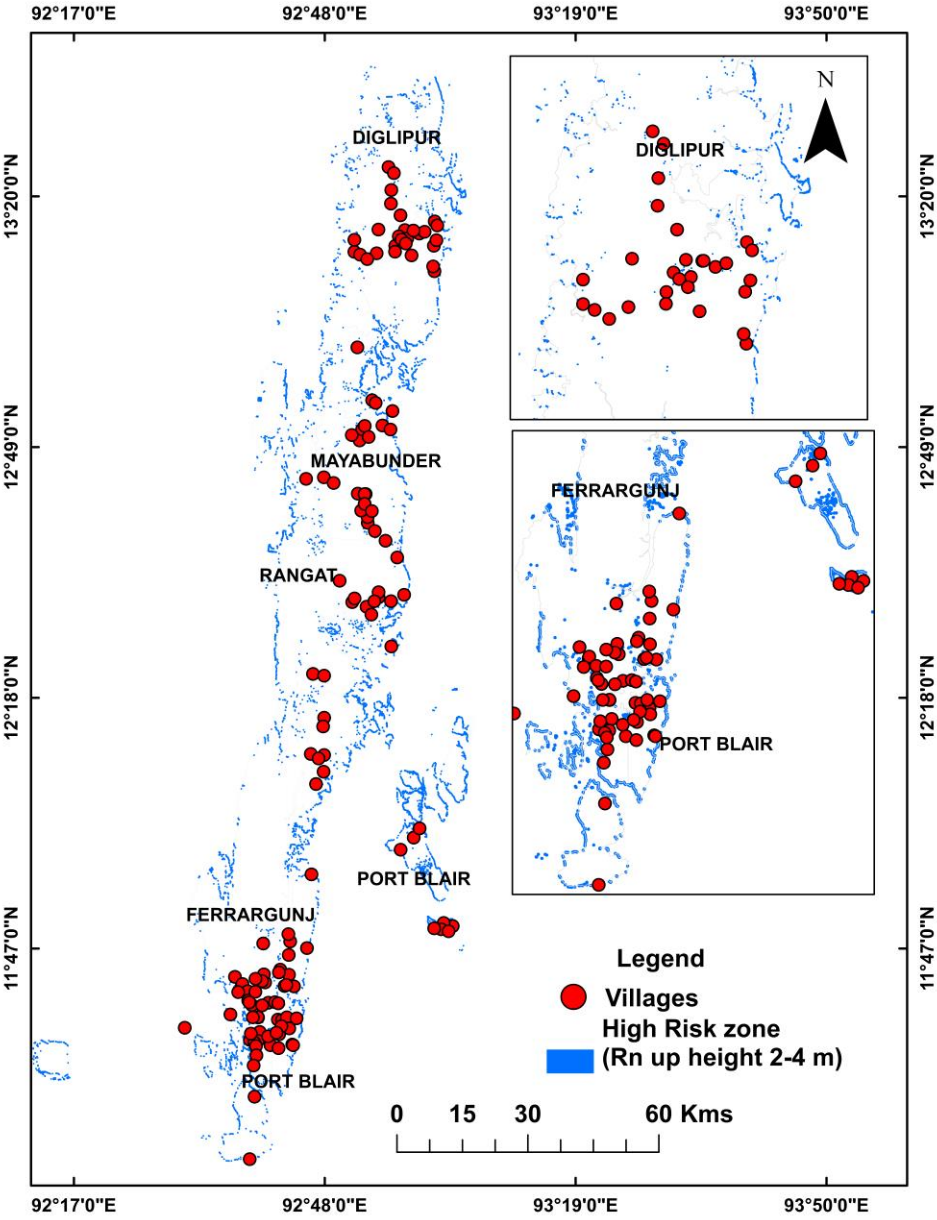


Fig 5.6b. Villages at risk of inundation during future flood scenario

movement to make Port Blair a free port. Following that, there was a significant focus on developing tourism, leading to the construction of numerous hotels, which made real estate unaffordable for the middle class in Port Blair. The fast population growth (Fig

5.6c.) has significantly impacted local resources. Numerous areas of the islands, formerly home to native tribes, are now occupied by migrating populations who have failed to adjust their lifestyle to the limited resources of the island environment (Patnaik,2012). Thus, rapid increase in urbanization, transport and communication

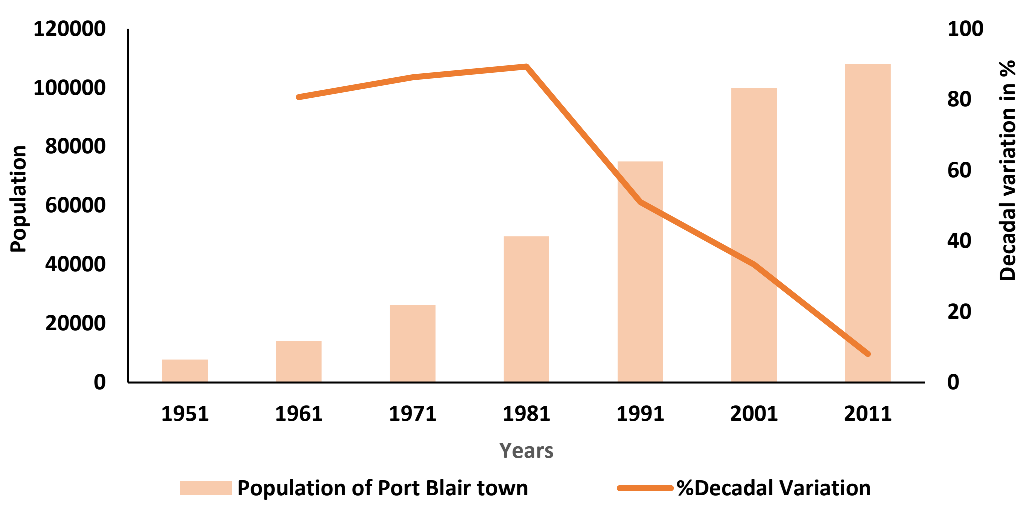


Fig 5.6c. Population Growth Blair town (1951-2011)

facilities, and developed road network facilitated the capital city, to cope against natural calamities and climate change threats. However, when considering rural areas when considering rural areas, Mayabunder and Diglipur are more vulnerable due to their relatively high population density. The study highlighted the critical need for proactive measures in villages located in densely populated areas to mitigate the risks of loss of life from extreme events and associated flooding. By implementing effective strategies and community preparedness, these villages can enhance resilience and protect their residents.

With 16128.6 hectares of cultivated land, and 139.87 hectares dedicated to pisciculture, agriculture is the primary economic activity in North & Middle Andaman. Diglipur and Mayabunder tehsils have a 100 percent rural population, with 42.8% and 33.9% dependency on agricultural activities respectively (Fig 5.6d i.). However, inadequate irrigation facilities and limited groundwater availability hinder vegetable and flower production, particularly during the dry season when tourist activity significantly increases. Additionally, inadequate farm mechanization, high post-harvest losses, and limited access to agricultural schemes have resulted in low-income opportunities for farmers and restricted their ability to diversify their income sources.

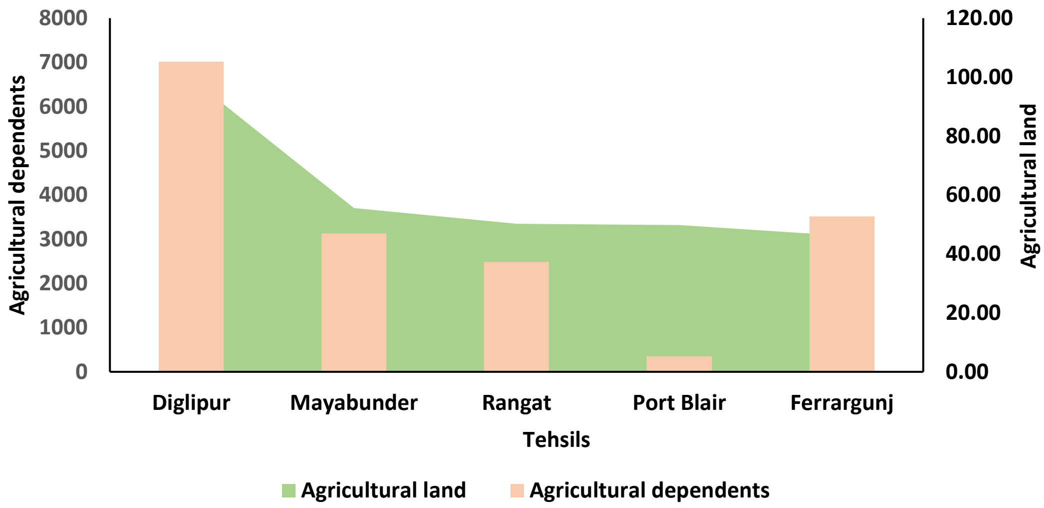


Fig 5.6d i. Tehsil wise representation of Agricultural dependents and amount of agricultural land in 2018

The island's remote location, lack of local expertise, technology, trained personnel, and capital investment in cost-effective marine fish production, have not only limited production to just 12% of the estimated potential but have also hindered the sector's economic growth and the overall welfare of fishermen. In terms of future flooding scenarios due to sea level rise or sudden Tsunami, agricultural zones of Port Blair and Mayabunder, are found at greater risk of inundation compared to cultivable lands of Diglipur owing to their generally higher elevation (Fig 5.6dii).

The Union Territory (UT) exhibits relatively strong human development indicators; however, it faces significant challenges such as stagnant per capita incomes and rising unemployment rates. Additionally, unemployment has particularly increased among women, and labor productivity has been on a decline since 1996-97 (Rai et al.,2006). In terms of the composition of the workforce, Mayabunder and Diglipur stand out as the most vulnerable tehsils, displaying a high percentage of non-workers, marginal workers, and agricultural dependents, as represented in Figure 5.6e

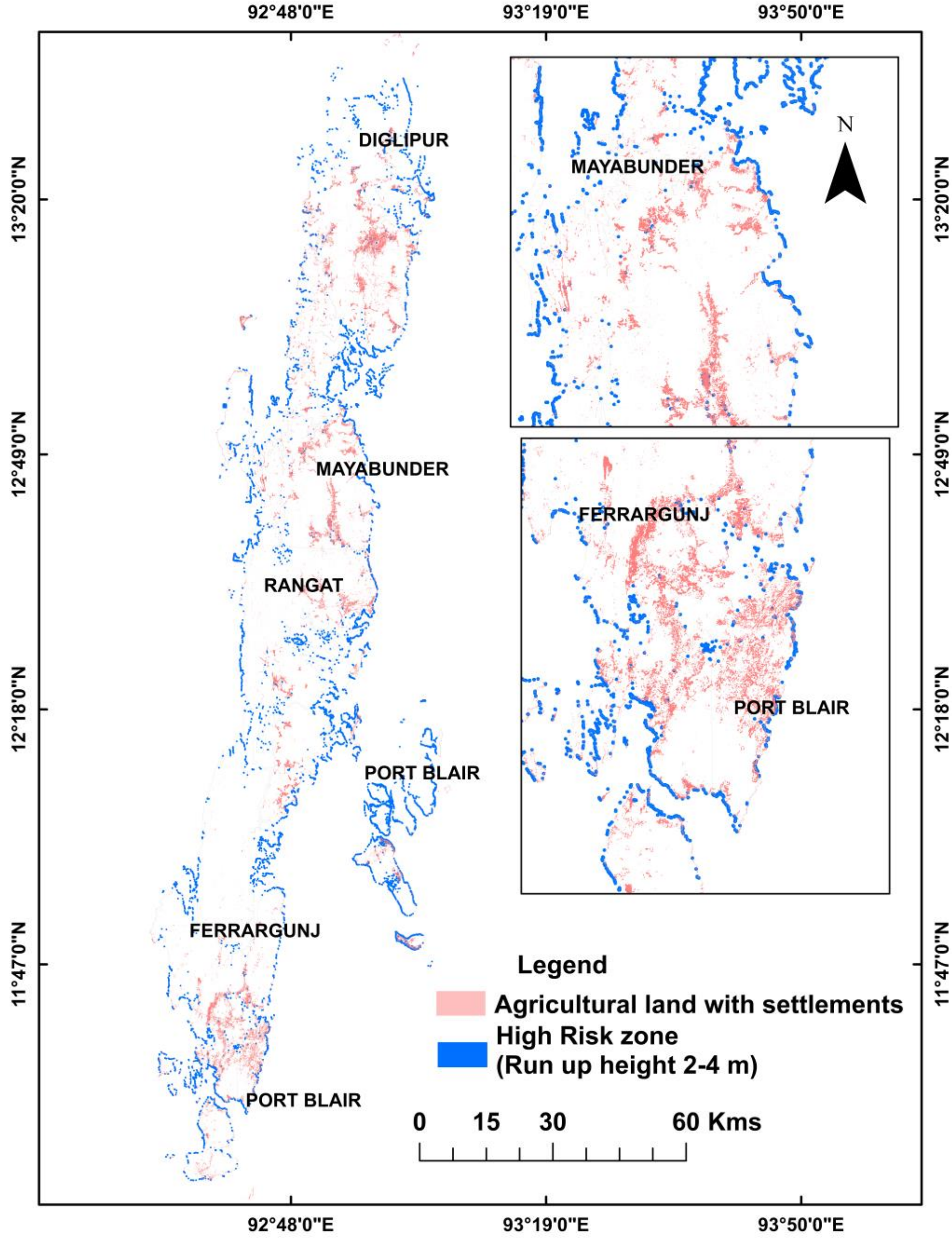


Fig 5.6d ii. Agricultural land under risk of inundation during future flood scenario

This stands in contrast to Port Blair, where the preponderance of the civilian populace is engaged in tertiary sectors, displacing traditional agricultural pursuits. Lesser industrial developments have led to limited job opportunities outside of the

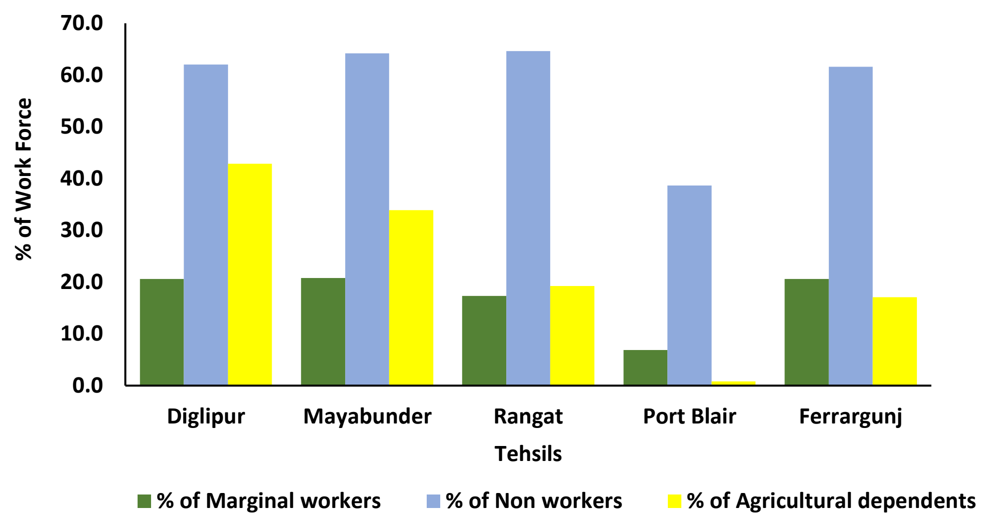


Fig 5.6e. Composition of work force in each tehsil of Andaman Island

government. The involvement of administration in economic activities, rather than serving as a facilitator has negatively impacted the monetary status of the province, leading to a shift towards more revenue expenditure and less growth, undermining the UT's growth potential. As a result, public expenditure has had limited impact on income generation (Rai et al.,2006).

There have been remarkable improvements in creating suitable educational infrastructures, but still a lot more needs to be undertaken to improve its quality. It is crucial to integrate information about the islands in the curriculum to raise children's awareness and sensitize them about the environment's fragility (Rai et al.,2006). Moreover, Government should promote technical and vocational skills within the workforce. Training that is directly linked to employment offers clear advantages over traditional educational training. Employers are more aware of the current labour market needs and technological advancements in various fields than formal educational institutions (Rai et al.,2006).

Although the 2004 Tsunami hit Port Blair, it is ranked as the least socially vulnerable tehsil due to its high adaptive capacity. This is measured in terms of having the highest number of medical facilities and educational institutions among other factors. The district is also the most urbanized and has better connectivity with the mainland and the rest of the region. As the capital of the Union Territory, Port Blair enjoys advantages in terms of livelihood, grid electricity, water resources, and household assets. Furthermore, the people residing in Port Blair are primarily ration, social security, and economic prosperity compared to other sectors. engaged in the organized sector, which ensures a secure and fairly high-income gene

The island territories are undeniably facing significant water stress, primarily due to current rainfall levels and groundwater extraction practices. Water pollution poses a serious threat to human health, directly contributing to a rise in water-borne diseases. The unique characteristics of these small islands—limited size, varied geology, and distinct topography—make their water resources highly susceptible to climate variations, especially shifts in rainfall patterns. As tourism continues to grow rapidly, it is imperative to expand and manage existing water resources (A&N Islands Action Plan on Climate Change, 2013). The heavy reliance on seasonal rainfall exposes the islands to potential vulnerabilities linked to future shifts in precipitation. Inadequate rainfall can greatly diminish water harvesting capabilities, decrease river flow, and slow the recharge rates of freshwater sources, leading to prolonged periods of drought. It is clear that these issues require immediate attention and action to safeguard the water resources of island territories (ibid).

Based on the 2001 census, only about 340 out of 502 villages had full access to public water provision whereas maximum villages of Diglipur did not have access to safe drinking. Although the A&N Islands receive ample rainfall, there is no specific policy for rainwater harvesting, which means the region is not fully taking advantage of this natural resource. A holistic approach to water harvesting is essential. Feasibility studies are underway in diverting sea water of Flat Bay into a lake to meet long-term drinking water needs. The successful implementation of desalination technology in Lakshadweep should be replicated in A&N Islands (ibid)

The archipelago currently depends on diesel-generated power to meet their electricity requirements. The electricity department oversees power distribution to all consumers in the ANI. However, there are rising concerns about the ability to satisfy the increasing demand for electricity on the islands (Sridhar et al., 2020). Per capita electricity consumption has risen sharply, with the Central Electricity Authority projecting peak demands of 111 MW, 226 MW, and 323 MW for the years 2015/16, 2021/22, and 2026/27, respectively. To tackle this growing demand, it is crucial to consider alternative, low-cost electricity generation methods. Relying solely on thermal power stations using coal or diesel could impose a significant financial burden unless new resources are discovered. Additionally, pollution from fuel sources poses a threat to the islands' natural resources. Hydropower options are limited due to absence of streams. Another challenge is the distribution of energy to remote islands, particularly following the Supreme Court's decision against the installation of distribution lines in tribal reserves. Supporting evidence from the current study shows that many households in rural North Andaman lack access to electricity. The diverse habitats necessitate a mix of energy strategies tailored to local needs and opportunities. Encouraging households and institutions to implement rooftop solar power systems could also help them meet their specific energy demands.

The advancement of infrastructure and facilities can significantly mitigate negative environmental impacts. In terms of access to essential infrastructure, urban areas such as cities typically witness fewer casualties than rural regions. This study concentrated on evaluating the vulnerability of infrastructure, road systems, and cyclone shelters. Effective transportation and communication systems are vital for evacuation and disaster management. A considerable portion of study area demonstrates very high level of vulnerability regarding transportation access. While Port Blair and Ferrargunj were classified as having low to very low vulnerability, Rangat and Diglipur showed very high and high vulnerability, respectively. The research indicated that the urban and agricultural zones of Port Blair, Ferrargunj, and Mayabunder are well-connected through road and air networks, while the rural roads in Rangat and Diglipur require further development. This study contributed to the formulation of location-specific emergency plans and strategies to confront eminent threats. This includes proper forecasting system for extreme events and spreading these forecasts at the grassroots level. Furthermore, constructing multifunctional relief camps would help the affected communities. Other adaptation plans encompass various livelihood development initiatives, ecotourism, skill development programs, hazard preparedness, and capacity-building efforts. According to the study, the social status of residents emerged as the most noteworthy statistical parameter to fight against disturbances. Consequently, policymakers should guaranty the availability of potable water, primary healthcare, education, continuous electricity for every household can greatly reduce the vulnerability of socially marginalized populations to disasters while also improving their overall quality of life. (Fig 5.6f).

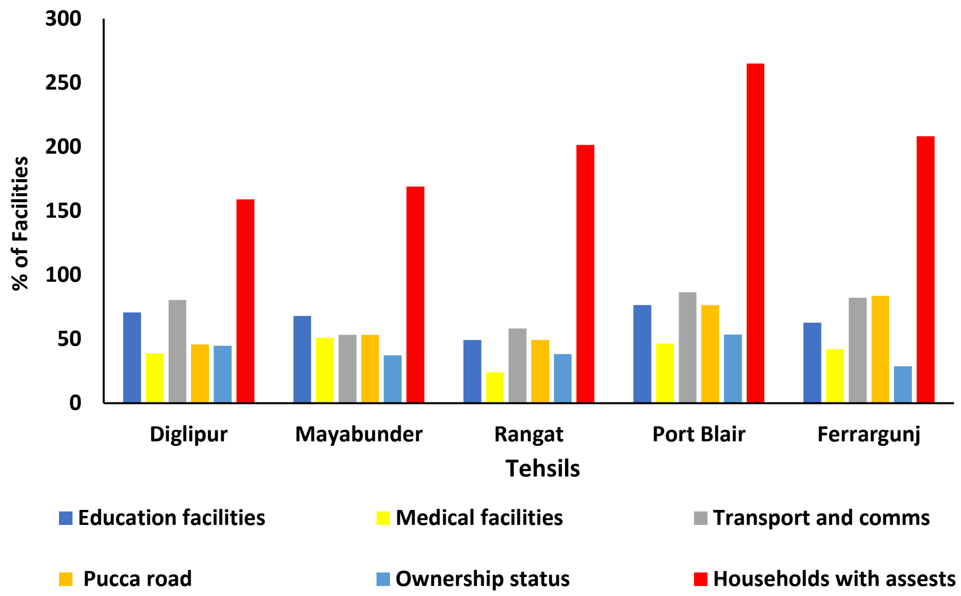


Fig 5.6f Availability of basic amenities in each tehsil to serve as adaptation mechanism against climate change stressors

The analysis indicated that the northern part of Andaman Island is more socio-economically vulnerable than the southern part and ill-equipped to recover from various hazards unless appropriate adaptation measures are taken along with a disaster risk reduction framework.

Based on Hahn et al. (2009), a vulnerability triangle was plotted to represent exposure, sensitivity, and adaptive capacity, where higher vulnerability spans over the larger part of the triangle. Figure 5.6g. clearly illustrate the impact of contributing factors, as indicated by IPCC (AR 4), on the vulnerable tehsils of Andaman. Notably, tehsils such as Diglipur, Mayabunder, and Ferrargunj are deemed to be at the extreme risk because of complex exposure, sensitivity, and less adaptive capacity

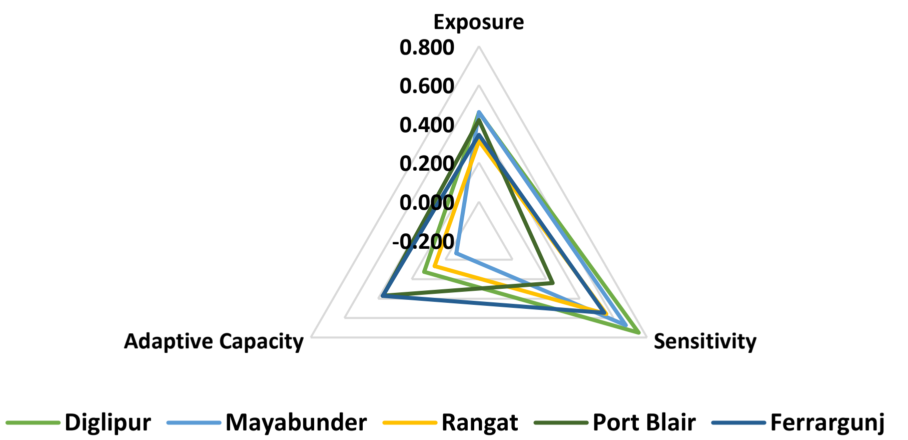


Fig 5.6g. Vulnerability Triangle representing exposure, sensitivity, and adaptive capacity

5.7 Conclusion

The study demonstrated that while concerted efforts for adaptation, systematic planning, and infrastructural development can reduce social vulnerability, ongoing threats of changing climatic conditions necessitate continuous assessment and monitoring.

The analysis indicated that the northern part of Andaman is more socio-economically vulnerable and exposed to the highest risk compared to the central or southern part of the island. Diglipur, with its predominantly rural population and primary agricultural activity, is more susceptible to natural hazards than other tehsils like Ferargunge or Port Blair, where urbanization and development mitigate vulnerability. Inadequate water supply for irrigation, insufficient drinking water, poor toilet and electricity infrastructure pose major threats to the coastal livelihoods of Diglipur, Mayabunder, and the Rangat region. The study concludes that any adaptation schemes or planning should go beyond ordinary development activities due to ongoing climate change trends.

CHAPTER-6

ASSESSING FUTURE CORAL BLEACHING EVENTS AND STRENGTHENING THE SUSTAINABILITY OF COASTAL FISHERIES IN THE ANDAMAN ISLANDS IN RESPONSE TO CLIMATE CHANGE.

6.1 Introduction

Around 28% of India's Exclusive Economic Zones (EEZ) belongs to A& Nicobar Islands, (Advani et al, 2013). In 2017–18, around 39284 tonnes of fish were harvested from the nearby coast (ANI Fisheries Policy 2018). the fishery resources found in open oceans remain largely untapped (Dam Roy et al. 2009; Kiruba-Sankar et al. 2019). Out of 1,434 species documented in the islands, 75.68% are associated with coral habitats (1,089 species) (Dam Roy and George, 2010). Figure 6.1 illustrates some of the key fish landing sites in Andaman Islands which is our study area . Although the catches of various species, such as perch, silver bellies, or neritic tuna, appeared to be influenced by the bleaching events of 1998, 2005, 2010, and 2015–16, no clear conclusions could be drawn due to insufficient data on fishing efforts (Rajan et al.,2013)

In the year 1970, Indian Government implemented measures to enhance the fisheries sector in the islands by offering free housing, fishing equipment, concessions, and other benefits to attract fishermen from the mainland to relocate especially the Telegu, Tamil and Bengal migrants. These newcomers, now regarded as locals, represent a total population of 22,188 across 134 villages within the Union Territory. They engage in three main fishing activities: commercial fishing, offshore fishing, and aquaculture. Most fishing operations take place in the coastal regions of the islands where maritime resources represent 50% of the overall catch, which is the mainstay of the marine fishery sector in the bay islands, followed by demersal fish catches. In contrast, the fish stocks in offshore and deep-sea areas remain underutilized (Kaliyamurti et al., 2020; Fisheries Policy, 2018). The fishing fleets are limited, and there is inadequate infrastructure and technical know-how for the storage, processing, and transportation of resources. Additionally, trade barriers between the islands and the mainland contribute to the lack of comprehensive resource data and coordinated action plans. Consequently, the resources in these islands have not been fully exploited (Dam Roy and George, 2010).

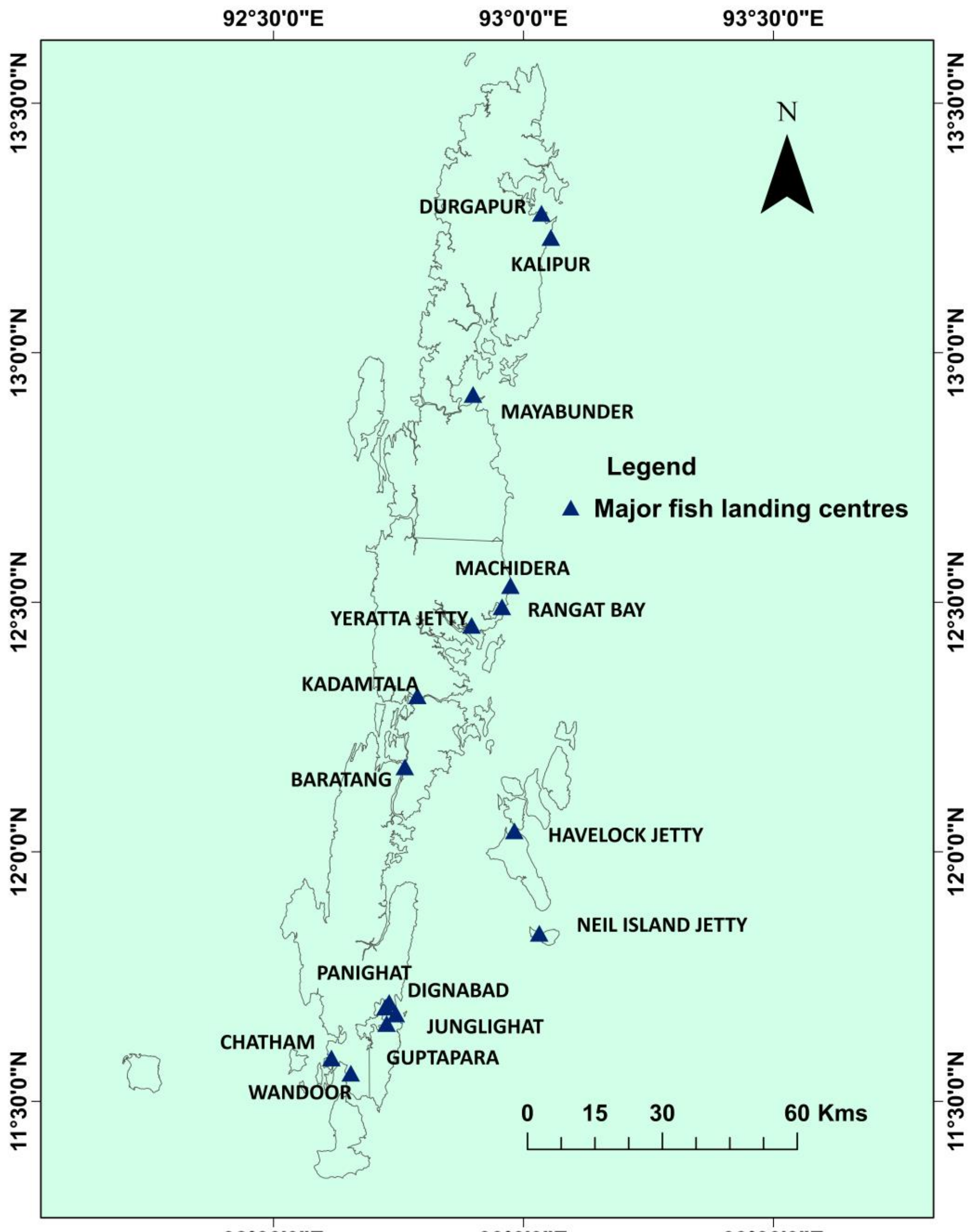


Fig 6.1 Major Fish landing centres of Andaman Island

6.2 Fish production and development of fisheries sector

According to recent estimates, the level of exploitation of pelagic and demersal fish stocks has exhibited a consistent increase from 16310 and 14213 metric tonnes, respectively, during the 2003-2004 period to 19478 and 1713 metric tonnes during

2017-2018. A gradual increase in tuna resources, with 181 metric tonnes was recorded in 2015-2016 though the exploited stock across all sectors falls below the potential yield. Specifically, only 5.02% of the potential 60,000-tonne yield for oceanic resources was utilized in 2015-2016. Since 2003-2004, marine stock has grown steadily barring fluctuations caused by the 2005-2006 Tsunami (Table 6.2a) (Andaman and Nicobar Islands Fisheries Policy,2018).

Table 6.2a. Marine fish production in metric tonnes over the period (2003-2018) (Environmental Impact Assessment Report 2018)

Year	Demersal	Pelagic	Oceanic	Total
2003-04	14213	16310	535	31058
2004-05	9178	8420	167	17765
2005-06	6394	5505	154	12053
2006-07	13790	14649	161	28600
2007-08	13894	14433	528	28855
2008-09	14585	16658	1092	32335
2009-10	15028	15200	2772	33000
2010-11	15039	16276	2420	33735
2011-12	15409	16495	3168	35072
2012-13	15863	17295	3268	36426
2013-14	17005	18454	1294	36753
2014-15	16329	18231	2420	36980
2015-16	15405	18704	3016	37125
2016-17	16543	18978	3060	38581
2017-18	16731	19478	3075	39284

There is an obvious dearth of mechanized fishing, with existing motorized crafts operating only a few kilometres from the coast EQMS,2018) (Table 6.2b.). As a result, the Andaman fishery policy of 2018 mandated the commencement of mechanized fishing using various vessels beyond 6 nautical miles (Fig 6.2) Gill net comprises around 40 % of the total equipments, while line and hook makes up 34%. These gears primarily exploit coastal small to medium pelagic fish and are unsuitable for deeper areas. To effectively target tuna resources, it is imperative to introduce new designs of gillnets and hooks and lines (Pillai and Abdussamad, 2009). The islands are devoid of mechanized fishing, with existing motorized crafts operating only a few kilometres from the coast EQMS,2018) (Table 6.2b.). As a result, the Andaman fishery policy of 2018 mandated the commencement of mechanized fishing using various vessels beyond 6 nautical miles (Fig 6.2)

Table 6.2b. Year wise fishing boat details of Andaman and Nicobar Islands (Environmental Impact Assessment Report 2018)

Years	Motorized	Mechanized	Non-motorized
2006-07	1274	5	1524
2007-08	1257	12	1451
2008-09	1257	12	1451
2009-10	1431	63	1620
2010-11	1293	55	1465
2011-12	1444	72	1611
2012-13	1484	59	1604
2013-14	1481	43	1591
2014-15	1352	68	1510
2015-16	1385	69	1528
2016-17	2006	114	1453

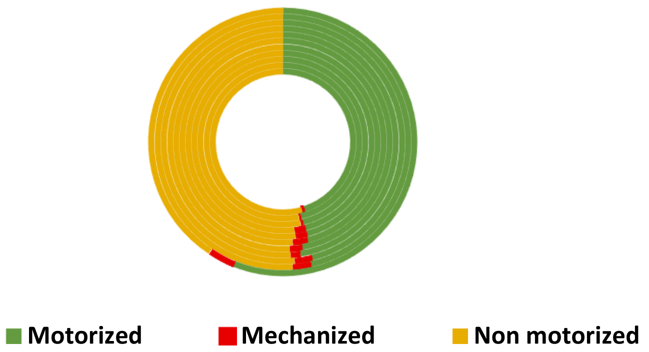


Fig 6.2 Fishing boat statistics of Andaman and Nicobar Islands

Gill net comprises 39% of the total fishing gear units, while hook and line makes up 34%. These gears primarily exploit coastal small to medium pelagic fish and are unsuitable for deeper areas. To effectively target tuna resources, it is imperative to introduce new designs of gillnets and hooks and lines (Pillai and Abdussamad, 2009).

6.3 The role of coral reefs in supporting fisheries amidst a changing climate.

Six million people around the world rely on reef fish which are worth 6 billion Dollars (Teh et al., 2013). Coral reefs are pivotal biodiversity hotspots that provide essential ecosystem services to millions of people (Cinner et al., 2016; Woodhead et al., 2021). However, long-term natural environmental fluctuations and short-term human-actions have deterred the reef's ability to serve properly. Local factors such as pollution and overfishing complicate the situation, exacerbating coral loss in specific regions, although quantifying these impacts remains challenging (Precht et al., 2020; Darling et al., 2019). It is essential to build up strong knowledge about these pressures for setting effective recovery targets and predicting the socio-economic and greenhouse gas emission scenarios that will influence future societies (Cisneros-Montemayor et al., 2021; Lam et al., 2020; IPCC, 2019).

Globally, oceans are experiencing instabilities in temperature, rain, currents and wind, due to variations in temperature and humidity. As a result, key weather-related patterns such as El Niño and monsoons are also being impacted by warming of ocean and climate change (Vivekanandan, 2011). The climate models in the IPCC, 2014 report projected that under their lowest and highest emissions scenarios, global surface temperatures could rise by 0.3 to 1.7 °C and 2.6 to 4.8 °C, respectively, during the twenty-first century (Zacharia et al. 2016). The mangroves and corals are significantly affected by changes in sea level, sea warming, and precipitation. A rise in sea surface temperature can impact fish spawning and physiology, or deviations in larval distribution (Vivekanandan, 2011; Shiva Shankar et al., 2021).

Prolonged elevated sea surface temperatures (SST) can subject coral reefs to severe thermal stress, leading to bleaching and mortality and considerable 10% increase in the metabolic activities of (Liu et al. 2003; Vivekanandan and Pandian 1977). Mass coral bleaching (MCB) events at regional scales have been globally documented since 1980 (Eakin et al. 2009), with notable impacts during occurrences such as 1997–98, 2010, and 2015–16, which were linked to El Niño–Southern Oscillations (Arora et al. 2019). Climate change-induced coral bleaching and subsequent loss could generate devastations on the topographic complexities, thus affecting the fisheries in those areas (Spalding et al. 2001; Wilson et al. 2006; Parmesan, 2006; Munday et al. 2008; Pratchett et al. 2008). Vivekanandan et al. (2009) predicted that reefs would be relict by 2040 in the Lakshadweep and by 2060 in the adjacent parts of Indian Ocean.

6.4 Sea surface temperature: powerful factor behind coral bleaching

Nearly all documented coral reef bleaching events have been linked to high temperatures as the primary stressor. Reef corals and their symbiotic algae, zooxanthellae, are found in the shallow waters of the photic zone (Baker et al., 2008). When water temperature surpasses the maximum seasonal threshold, coral bleaching occurs. A similar bleaching event was observed in July 1998, affecting massive and branched corals in three sites: Ross Island, North Bay, and Marina Park (Ravindran et al., 1999). While several studies over the last few decades have linked warming with loss of coral pigment (Stone et al.,1999; Glynn, 1991; Hoegh-Guldberg et al., 2007), ENSO is responsible for intensifying reef mortality in the eastern Pacific Ocean (Podestá and Glynn, 1997) and Palau (Lix et al.,2016; Bruno et al., 2001),

The Andaman Islands experienced varying degrees of bleaching in 2002 and 2005. In 2002, the temperature ranged from 31.6 ◦C to 32.2 ◦C in the last half of April and from 31.3◦C to 31.9◦C in the first week of May. In the year April 2005, the weekly SST ranged between 30.8 ◦C and 32.2 ◦C in the last three weeks, decreasing to 29.8 ◦C during early May (Majumdar et al.,2018) as plotted in Fig 6.4. These observations indicated warming of water masses and prevalence of bleaching of corals during the same period (Krishnan et al., 2011). In 2005, a patchy bleaching of 7.5% was recorded in North Bay in the month of April-May 2005.

The rise in temperature of tropical oceans by more than 3°C, led to widespread bleaching of Indian reefs, particularly those in the Andaman Islands in 1997-1998 (Ravindran et al.,1999). In March 2010, degree heating week temperatures above 10°C weeks and Hot Spot temperatures over 2°C were observed in the Andaman Sea, which lasted for 5 to 6 months (Tun et al., 2010). Between April and May 2010, Central Pacific Eastern Pacific El Niño triggered bleaching affected 37% to 70% of corals. Sea surface temperature (SST) ranged from 31°C to 32°C at the end of April, and then rose to 33°C in the first week of May (Krishnan et al., 2011) (Fig 6.4). Sarkar and Ghosh (2013) conducted a study in Havelock, Chidiyatapu, Ross, North Bay, and Jolly Buoy islands. They found that the 2010 bleaching events not only affected the reef builders but also sea anemones and giant clams. Southern sections of Andaman recorded maximum rate of colour loss-87.45% where it occurred at a depth of 5–15 m (Mondal et al., 2014, Majumdar et al.,2018). Mohanty et al. (2017) analysed the Degree of Heating Weeks (DHW) and Hotspots using SST data in the surface waters of the Andaman and Nicobar Islands. AVHRR). It was observed that the reefs of the North Bay region showed signs of bleaching, with in-situ temperatures ranging between 31.8°C - 32.3°C between March to April.

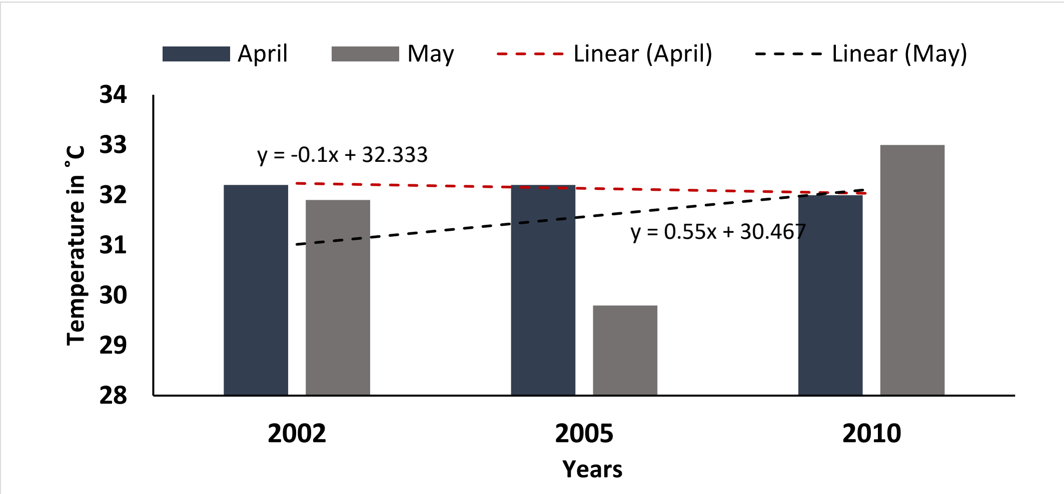


Fig 6.4 Sea surface temperature recorded for the three bleaching years for the months April and May

To plan fishery activities, a reliable climate model that can predict future bleaching events is imperative. While global climate models (GCMs) are useful for providing climate change information, they have limited grid sizes. Regional climate models (RCMs) are helpful because they can downscale global climate simulations to smaller grid sizes in specific areas of interest. This allows for more detailed and accurate climate predictions in the Andaman Region. The emission scenarios of IPCC AR4

(IPCC 2007) were developed based on economic, environmental, and sustainable factors for both developed and developing nations. The AR5 scenarios were built on anthropogenic radiative forcing. Each model uses different approaches to determine the four radiative forcings, which correspond to different concentration paths of greenhouse gases- Representative Concentration Pathways (RCP) (IPCC,2014). There are four specific RCP scenarios, linked to four levels of radiative forcing: RCP 8.5 (8.5 W/m^2), RCP 6.0 (6.0 W/m^2), RCP 4.5 (4.5 W/m^2), and RCP 2.6 (2.6 W/m^2) (Akhiljith et al., 2019). The study definitively utilized the CNRM-CM5 model to identify coral bleaching events, detailing their frequency and intensity, and assessed the profound stress these events impose on the fisheries that rely on these vital coral ecosystems (Majumdar et al., 2022).

6.5 CNRM CMIP -5 Global Climate Model

Coupled Atmosphere-Ocean General Circulation Models (AOGCMs) is valuable for understanding spatiotemporal changeability, and predictability of climate and for making future climate projections. While these models have seen improvements in realism over the past decades, they still exhibit significant biases, contributing to uncertainties in weather predictions (IPCC report 2007). The Coupled Model Intercomparison Project (CMIP) allow users to systematically analyze Global Climate Models.

The CMIP5 project involves 20 climate modelling research groups worldwide, utilizing 40 GCMs. These simulations based on different senarios of radiative forcings provides crucial data regarding greenhouse gases and aerosol present in the troposphere and stratosphere, which are essential for driving coupled ocean-atmosphere climate models (Haywood et al.,2014; Voldoire et al.,2013, Moss et al.,2010

6.6 HadGEM2- ES model

HadGEM2, represents a sophisticated model designed with varying levels of complexity while adhering to a shared physical framework. Among the HadGEM2 configurations is a coupled atmosphere-ocean model, which can include or exclude a detailed stratospheric component. HadGEM2 Earth system model integrates ecosystem components such as TRIFFID and Diat HadOCC, which are essential for simulating the carbon cycle and its complex interactions with the climate system (Cox, 2001; Palmer and Totterdell, 2001). This multifaceted approach allows for more comprehensive climate simulations and analyses (Collins et al.,2008) and enables researchers to gain deeper insights into climate dynamics and informs effective climate change mitigation strategies.

The output of CMIP5 model was found to be more suitable for Southeast Asia and thus applied for Andaman Islands. HadGEM2-ES emphasizes high-end warming and detailed Earth system interactions, while CNRM provides moderate climate response, giving an ensemble that spans uncertainty in projections. Moreover both provide consistent historical and RCP-based simulations from 1950 to 2100, with sufficient temporal and spatial resolution for downscaling (https://www.metoffice.gov.uk/research/approach/modelling-systems/unified-model/climate-models/hadgem2).

6.7 Materials and Methods

We used a suitable CMIP5 model which was statistically downscaled under the appropriate RCP4.5 scenario, to analyze model projections for one of the most important oceanographic ocean temperatures up to 2100. The details of the methodology have been discussed in Chapter 2 Section 2.7.1-2.7.5

6.8 Results

6.8.1 Projected Temperature Changes

In the RCP 4.5 scenario, the SST projections showed moderate warming under both models. From 2006 to 2020, the SST trend indicated a temperature rise of +0.0240°C/yr in one model and +0.012 °C /yr in the second. Warming trend was projected to become steeper in the coming decades under CNRM-CM5 model until 2070, after which it became more subdued at around 0.011 °C yr−1. This led to an overall sea surface warming of 0.015 °C per year during this century (Fig 6.8.1a.). The HADGEM 2-ES model showed a lower initial warming trend of 0.012°C until 2050, followed by a steeper rise at 0.022 °C yr−1 (Fig 6.8.1b.). However, the observed temperature data set over the Andaman Islands suggested that the first model projection under the RCP 4.5 was more realistic and was used in the study for the projection of bleaching events.

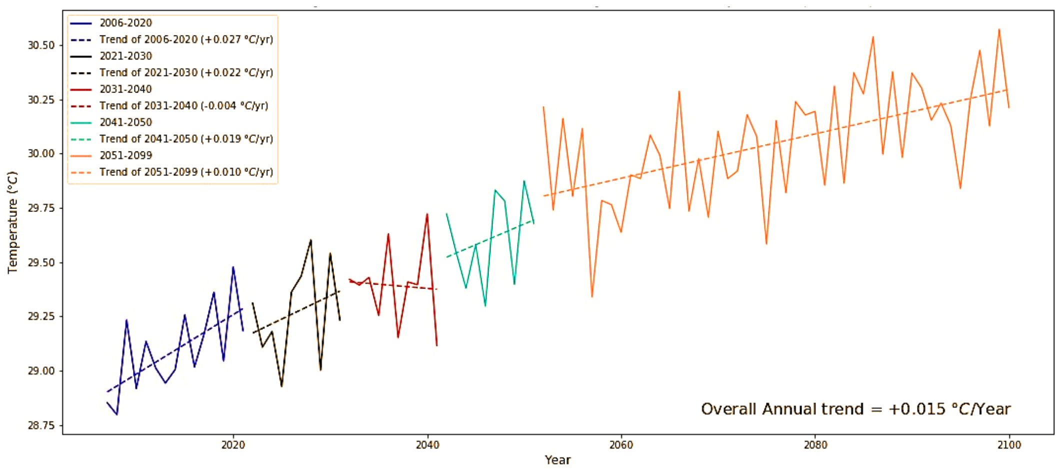


Fig 6.8.1a. CNRM-CM5 projection of future sea surface temperature around the study area

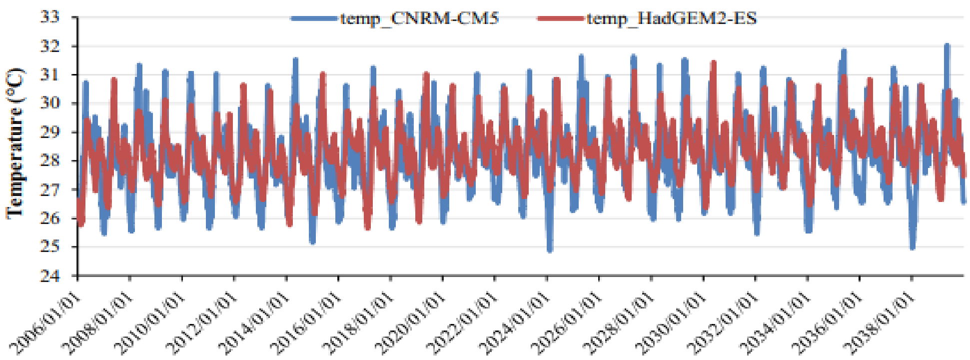


Fig 6.8.1b. Intercomparison of HadGM2-ES and CNRM-CM5 projections around the study area

6.8.2 Validation of Bleaching Events in Andaman from Temperature Records and Model Output

The assessment method and model efficacy were confirmed by targeting three mass bleaching events of corals caused by elevated sea surface temperatures. Field observations by various researchers validated the findings. Using the AVHRR dataset from 1982–2005 (Fig. 6.8.2a.), the maximum monthly mean temperature (MMM) was calculated to be 29.8°C. The value obtained by Arora et al. (2019) for the warmest month of May in Andaman aligned with our findings.

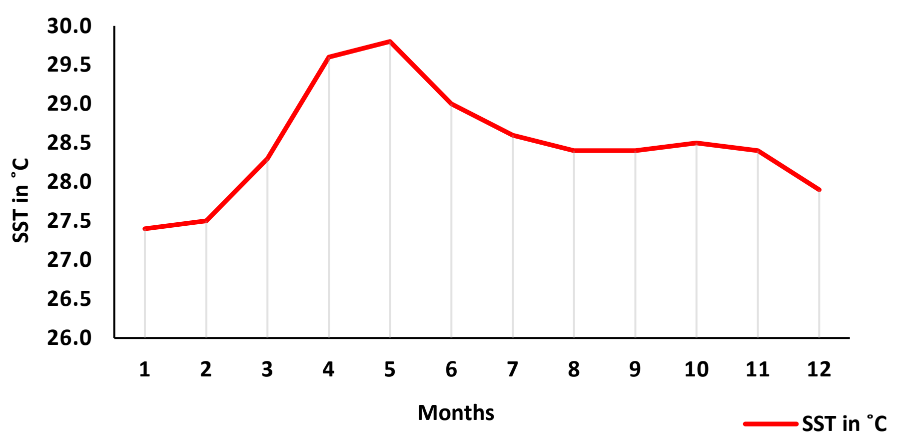


Fig 6.8.2a. Monthly average SST climatology from daily obs SST data of 1982–2005

Bleaching hot spots were identified when the observed sea surface temperature (SST) was at least 1°C above the MMM values, i.e., 30.8°C. The cumulative number of heating days, the bleached segment experienced was accurately calculated using the DHW method. Before forecasting future bleaching events, thorough assessments were conducted, comparing AVHRR data, MODIS data, CNRM-CM5 output, and HadGEM2-ES output with field observations published by various scientists from Andaman. The validation results, detailed in Table 6.8.2, confirmed the successful identification of the three most widespread bleaching events of 1998, 2005, and 2010 from both the AVHRR dataset and CNRM CM5 model output, along with subsequent calculations of DHW.

Table 6.8.2 Validation of bleaching events in Andaman assessed from satellite-derived SST data and model projections

Year	AVHRR		MODIS		RCP 4.5 CNRM-CM5		Validation in field
	Max (SST-MMM)	DHW	Max (SST-MMM)	DHW	Max (SST-MMM)	DHW	Ravindran et al. (1999
1998	1.9	1.89	No data		1.1	0.45	Krishnan et al. (2011)
2002	1.2	0.48			No event threshold		no reference found
2003	1.3	1.3	No event threshold		No event threshold		No reference found
2004	1.7	2	No event threshold		1.4	1.41	No reference found
2005	1.4	0.87	1.4	0.69	1.6	2.12	Krishnan et al. (2011) Sarkar and Ghosh (2013)
2010	2.2	9.83	2.2	5.65	1.3	2.7	Marimuthu etal.2013 Mondal et al. (2014) Mohanty et al. (2017)
2014	1	1.56	No event threshold		1.8	4	No reference found
2015	1.5	1.27	No event threshold		No event threshold		No reference found
2016	1.9	7.41	1.8	2.26	No event threshold		Mohanty et al. (2017)
2018	1.6	2.79	1.7	1.09	No event threshold		No reference found

The MODIS dataset, despite its limited observation period, was able to identify coral bleaching events in 2005, 2010, and 2016. Both MODIS and AVHRR observed mass coral mortality in 2010, with thermal variability reaching up to 9°C-week. While only the CNRM-CM5 model detected the 2010 bleaching event with limited intensity, the HadGM2-ES model completely missed it due to under-assessment of SST in the initial years. Here lies the advantages of intercomparison of different climate models to select the appropriate one for the region. Therefore, correcting the bias with AVHRR-derived data and using the CNRM-CM5 model projection would enable us to predict future bleaching events, their duration, and intensities around the Andaman Islands with more than 70% confidence (Fig 6.8.2b) (Majumdar et al.,2021). We can expect two intense bleaching events in the present decade in 2025 and 2029, and in the next decade in 2032 and 2035. By the 2040s, three intense bleaching events may occur, followed by more events in 2051, 2053, 2055, and 2058. The short intervals between these events do not allow the coral enough time to recover from the high-intensity thermal stress of bleaching events exceeding 8°C-week (Majumdar et al.,2022).

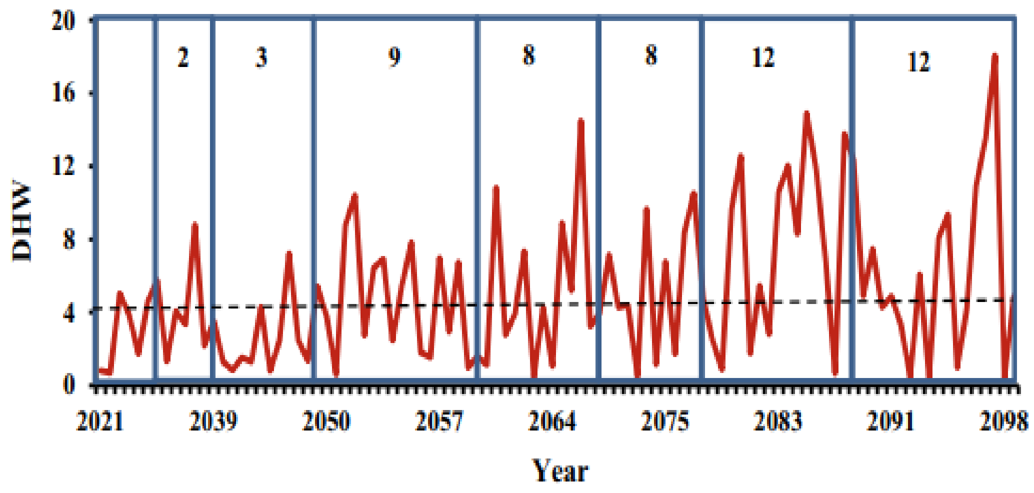


Fig 6.8.2b Projection of future bleaching events and their intensities (DHW) around Andaman Island using CNRM-CM5 model

6.9 Discussion

The study examined potential impact of sea temperatures on coral bleaching events and intensities. Additionally, the study aimed to provide a quantitative assessment of probable changes in such temperature and their trend (in RCP scenario 4.5) to understand their effects on the coral reefs and coastal fishery in the Andaman Region. Various researchers (Brown et al., 1996; Hoegh-Guldberg, 1999) have observed warming trends in the Indian seas, which have significant implications for marine fauna, particularly the vulnerable coral reefs that tend to lose their pigments when the temperature exceeds the seasonal maximum by just 1 °C (Majumdar et al., 2018). The study identified anthropogenic forcing, greenhouse gas emissions, warming and cooling events, IOD, and monsoonal winds as the primary factors contributing to ocean thermal variations (Jokiel and Brown, 2004, Majumdar et al.,2018Gnanaseelan et al., 2017; Yoo et al., 2006; Roxy et al., 2014). The analysis comparing monthly sea surface temperature (SST) data for 2030, 2050, and 2080 indicated that the highest SST increase occurred in April and May, leading to bleaching temperatures lasting for more than three days. While the period from 2001 to 2010 saw the most frequent bleaching events, the frequency could vary from 4 to 5 in the upcoming years.

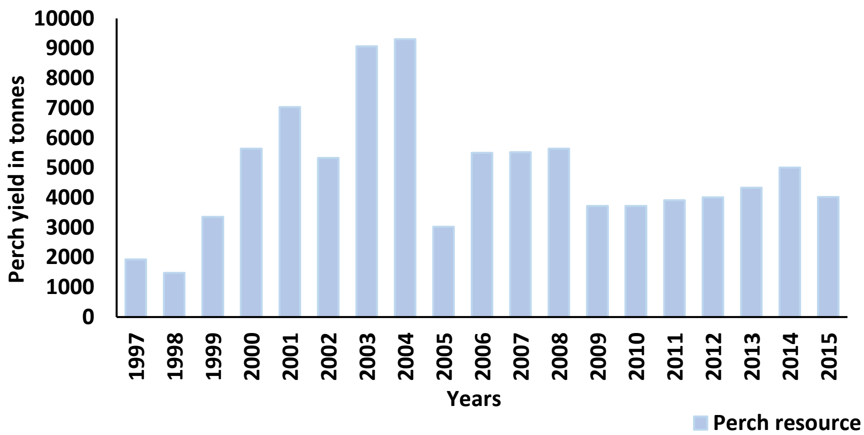


Fig 6.9a. Perch yield in tonnes (1997-2015)

Perch is a crucial fishery target in the Andaman Islands, with a total of 274 perch species recorded, including prominent ones such as Lutjanidae, Lethrinidae, and Serranidae (Anrose et al., 2010). During the years 1998, 2002, and 2005, the yield of perch drastically decreased compared to previous years. The decline in yield from 9303 tonnes in 2004 to 3019 tonnes in 2005 was almost 68%, which was attributed to both coral bleaching and the December 2004 Tsunami (Fig 6.9a.). Additionally high ocean temperatures recorded in March 2010 persisted for 5–6 months, with peak temperature increase occurring between April and June (Krishnan et al. 2011; Lix et al. 2016; Tun et al. 2010). Since July is the peak season for optimum catch, the yield was only 0.08% higher than the previous year in 2010. Furthermore, the year experienced significantly reduced rainfall (483.6 mm) (Krishnan et al. 2013), which could have otherwise helped revive the bleached reefs and thermally stressed corals.

Secondary fish catch data were obtained from Kaliyamoorthy et al.'s (2020) study of the ring operation of Andaman's fish landing centres for assessing the impact of the bleaching on reef fisheries in the year 2015-2016. Although the original data were collected over four years (2014-2018) from various important landing centres of Andaman, the current study focused on two previous years and the bleaching year of 2016 to emphasize the effect of bleaching on the catch. It was observed that in North Bay, the annual average fish catch per trip decreased significantly from 8110 to 1014 tonnes in the year 2016. Except for Havelock and Chiriyatapu, all other landing centres had lower catches per trip compared to the year 2015 (Fig. 6.9b.).

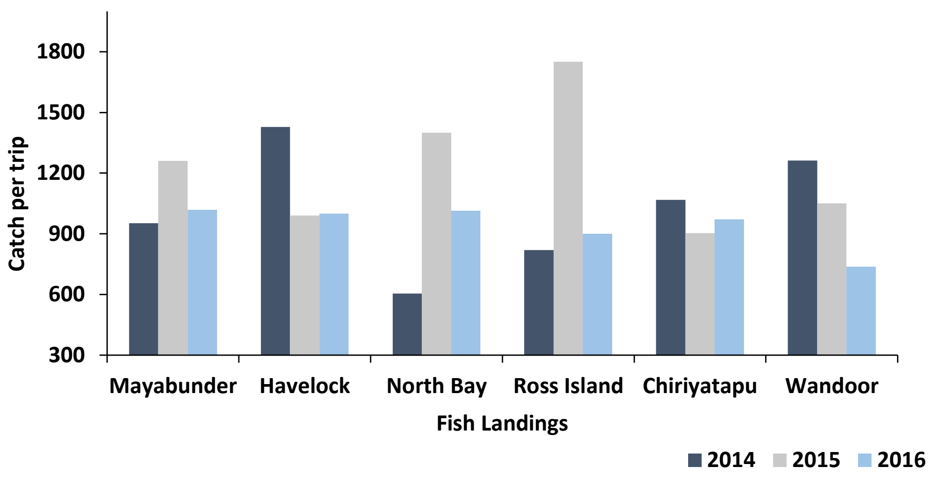


Fig 6.9b. Coastal fish catch per trip in landing centres of Andamans during before and after a bleaching event

6.10 Sustainable Fishing in the Time of Climate Change

Despite experiencing multiple bleaching events, fish stock exploitation has steadily increased from 31,058 to 39,284 metric tonnes between 2003 and 2018. Effective supervision primarily encompasses limiting access to economically valuable edible invertebrates, fish, ornamental species, and decorative shells for tourists (Rajan et al., 2012). Common management practices include providing certifying fishermen and their boats, banning use of outdated machineries, and restricting catch. Coral reefs support a diverse range of interests, including commercial and sport fishing, snorkelling, diving, research activities, glass-bottom boat tourism, and various other stakeholders. (Rajan et al.,2012).

6.11 Conclusion

The findings revealed a significant rising trend in sea surface temperature (SST) projections for the years 2030, 2050, and the 2060s. Additionally, there was an increasing trend in the occurrences of coral bleaching phenomena projected for the decades of 2030, 2040, and 2050-60. The study also observed a notable reduction in fish catch, particularly among perch species, in North Bay in 2016 compared to previous years. This reduction was consistent with observed instances of coral bleaching due to elevated temperatures (Mohanty et al., 2017). The information regarding climate projections and their potential impacts is valuable for effective adaptation planning. A primary strategy for adapting to these changes involves fishing further away from the reefs and the coast, as well as exploring deeper waters. Satellite-based fishing forecasts have already proven advantageous, leading to a significant increase in total fish catch in Potential Fishing Zones (PFZs). Although the island fisheries are currently underutilized, they are exhaustible resources, much like any other. Therefore, it is crucial to adhere to sustainable fishing practices. Given the high international demand for tuna and the islands' proximity to key tuna markets such as Singapore and Bangkok, any development in the fisheries sector should focus on the exploitation of untapped tuna resources. These resources have, so far, largely escaped the impacts of coral bleaching.

CHAPTER-7

STATUS OF TOURISM AND SCOPE OF ITS SUSTAINABILITY IN ANDAMAN ISLAND

7.1 Introduction

Tourism, like any economic activity, brings both profits and losses that need to be evaluated. A crucial aspect of tourism is the available space in the region and how it responds to tourist traffic. The significant growth of the tourism industry has led to a widespread agreement that tourism development should be sustainable. However, there is still debate on how to achieve this. Excess-tourism is closely linked to the concept of sustainable tourism and requires a direct response from all involved. Sustainability aims at responsible use of resources so that coming cohorts can also benefit from them (Witz and Wojcik, 2020).

After studying the current situation, including how COVID-19 has affected tourism and what the future may hold the National Tourism Policy in 2022 aimed to fund growth and success of tourism in New India. It outlines a clear plan for sustainable and responsible tourism development. The policy focuses on improving conditions for tourism both in India and abroad, helping tourism businesses, enhancing tourism support services, and developing different areas of tourism (National Tourism Policy, 2022)

7.2 Tourism in Andaman Island

According to the tourism statistics from the IP&T, A&NI Administration (2004), number of tourists visiting the islands was less in 1980 which crossed the five lacs in 2019-2020 (Table 7.2). The Andaman Islands are renowned for their natural beauty, and tourism primarily concentrates on specific areas. Port Blair, the capital town, holds historical significance and serves as the main entry point to the Andaman and Nicobar Islands, attracting a large number of visitors each year. Islands such as Swaraj Dweep and Shaheed Dweep (formerly known as Havelock and Neil) are particularly popular due to their proximity to Port Blair and improved transportation connections (Kumar, 2017). Additionally, other destinations like Baratang and Barren Islands have gained attention for their unique attractions, including the limestone caves and the active volcano, respectively (Kumar, 2017). (Fig.7.2).

Table 7.2 Tourist arrivals in Andaman Islands (Tourism Statistics of ANI,2016, EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008)

Years	Domestic Tourist	Foreign Tourist	Total Tourist	Annual Growth Rate		
				Domestic Tourist	Foreign Tourist	Total Tourist
1981	7500	2096	9596			
1982	8835	1170	10005	0.178	-0.442	0.043
1983	13444	1102	14546	0.522	-0.058	0.454
1984	14020	1817	15837	0.043	0.649	0.089
1985	16000	3152	19152	0.141	0.735	0.209
1986	20291	1264	21555	0.268	-0.599	0.125
1987	20942	1791	22733	0.032	0.417	0.055
1988	31591	2085	33676	0.508	0.164	0.481
1989	34589	3663	38252	0.095	0.757	0.136
1990	39967	2392	42359	0.155	-0.347	0.107
1991	32242	2248	34490	-0.193	-0.06	-0.186
1992	35817	2435	38252	0.111	0.083	0.109
1993	35000	1771	36771	-0.023	-0.273	-0.039
1994	50737	3798	54535	0.45	1.145	0.483
1995	64490	3849	68339	0.271	0.013	0.253
1996	67958	5796	73754	0.054	0.506	0.079
1997	73558	4724	78082	0.082	-0.185	0.059
1998	74732	4915	79647	0.016	0.04	0.02
1999	77448	6035	83483	0.036	0.228	0.048
2000	81432	4634	86066	0.051	-0.232	0.031
2001	85866	5249	91115	0.054	0.133	0.059
2002	90629	4707	95336	0.055	-0.103	0.046
2003	93899	4281	98180	0.036	-0.091	0.03
2004	105004	4578	109582	0.118	0.069	0.116
2005	30225	2164	32389	-0.712	-0.527	-0.704
2006	118580	9045	127625	2.923	3.18	2.94
2007	136015	10975	146990	0.147	0.213	0.152
2008	124439	12512	136951	-0.085	0.14	-0.068
2009	142045	13692	155737	0.141	0.094	0.137
2010	180781	14615	195396	0.273	0.067	0.255
2011	202221	15814	218035	0.119	0.082	0.116
2012	230733	14981	256237	0.141	-0.053	0.175
2013	315910	24507	258445	0.369	0.636	0.009
2014	292233	15581	302381	-0.075	-0.364	0.17
2015	313265	12553	311358	0.072	-0.194	0.03
2016	421846	16012	400018	0.347	0.276	0.285
2017	498473	15766	514239	0.182	-0.015	0.286
2018	498784	16439	515223	0.001	0.043	0.002
2019	507528	13221	520749	0.018	-0.196	0.011
2020	80326	968	81294	-0.842	-0.927	-0.844
2021	82429	1504	83933	0.026	0.554	0.032

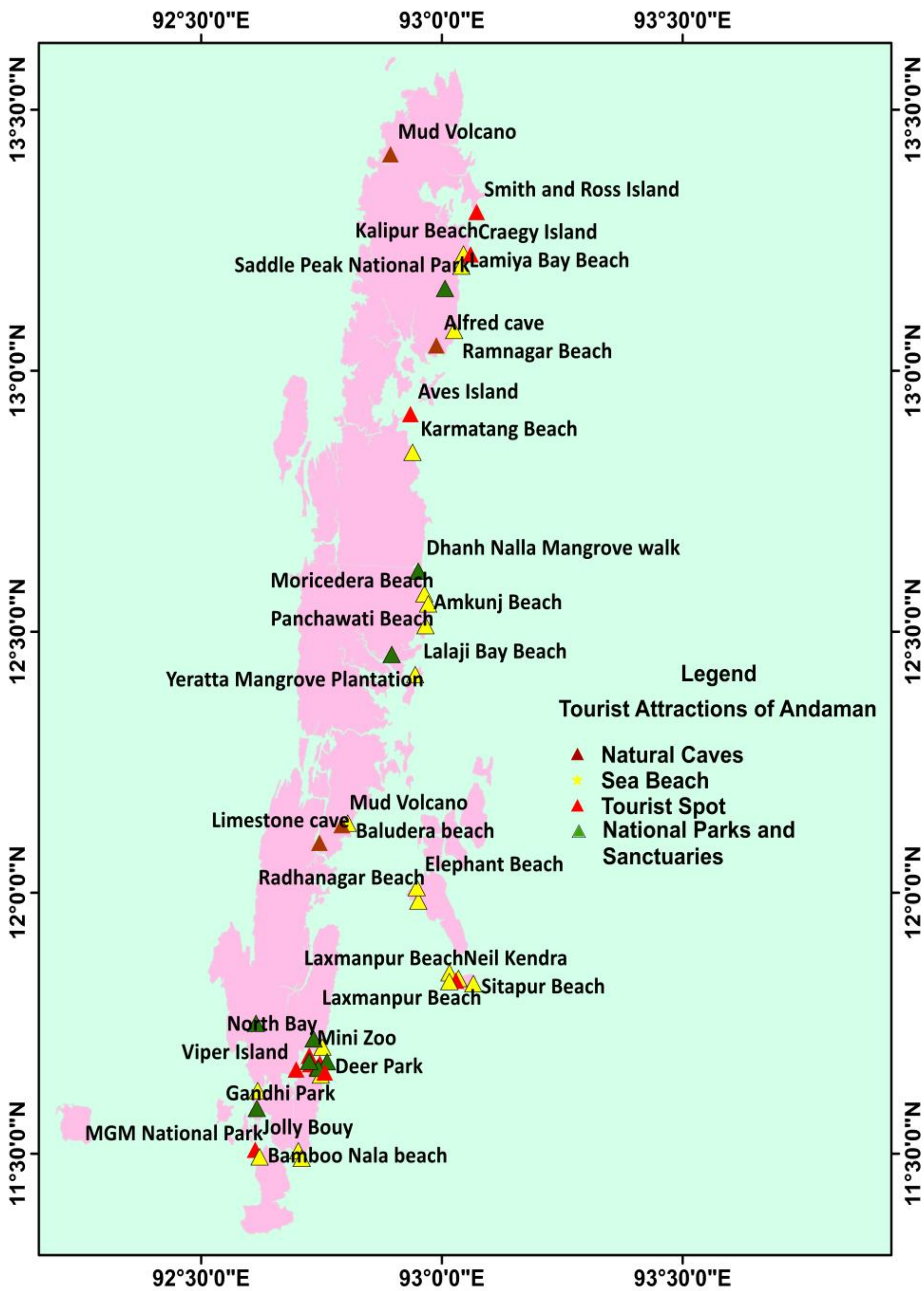


Fig 7.2 Popular tourist spots of Andaman Island

7.3 Methodology

A detailed description of the method has been carried out in Chapter 2 section 2.8.1-2.8.4

7.4 Results

7.4.1 Analysis of Tourism Area Life Cycle Stages:

Table 7.4.1 Compliance Assessment of indicators for various stages of TALC

Stages	Indicator	Compliance	Year
Exploration	Small tourist Number	yes	1981-1993
	Natural and cultural attractions	yes	1981-1993
	Physical and social fabric not disturbed	yes	1981-1993
	tourism does not affect the locals	yes	1981-1993
	No tourist facilities	yes	1981-1993
	High contact with locals	not found	
Involvement	Increase in the number of tourists	yes	1993-2004
	Public investment in infrastructure and transportation	yes	1993-2004
	Emergence of seasonality	yes	1993-2004
	Regularity in visitor number	not found	
	some advertisements to attract tourists	not found	
	change in the lifestyle of residents	not found	
Development	Rapid growth in visitation	yes	2006-2015
	External control and development	yes	2006-2015
	Government's involvement in planning	yes	2006-2015
	Local antagonism	not found	
	Auxiliary facilities for tourism (laundry, pharmacy, clinics	yes	2006-2015
	tourist market area	yes	2006-2015
Consolidation	Decrease in the growth rate of tourist number but an increase in tourist numbers	yes	2019-2019
	Total visitor numbers more than the population	yes	2019-2019
	Considerable emphasis on marketing and advertising	yes	2019-2021
	Local efforts may extend the tourist season	not found	
	Many hotel chains and franchise are represented	yes	2016-2019
	Locals not involved in tourism feel discontent	yes	2016-2019
Stagnation	Heavy reliance on repeat visitation	yes	2016-2018
	Peripheral development of tourism	yes	2016-2018
	More artificial/manmade attractions	yes	2016-2018
	Environmental, social and economic problems	yes	2016-2018
	Frequent ownership change	not found	
	Psycho-centric tourist / organized mass tourist	yes	2016-2018
	Low occupancy	not found	
Decline	Decrease in the number of tourists	yes	2005,2019-2021
	The decrease in the average stay of tourists	yes	2005,2019-2021
	Declining market	yes	2005,2019-2021

In conducting the evaluation process, a compliance assessment was carried out meticulously, based on publicly available data. This involved organizing the information obtained from credible sources in a chronological manner to pinpoint significant events corresponding to each stage. While the present study wasn't able to capture all the indicators outlined by Butler for Andaman Island, it effectively documented those that pertained to the island's tourism in Table 7.4.1.

The TALC for domestic tourists is depicted in Fig 7.4.1a. The Life Cycle progressed through several phases: exploration (1981-1993), involvement (1994-2004), development (2006-2014), consolidation (2016-2019), and two decline phases in 2005 and 2020-2021 for domestic tourists. The decline phases were marked by natural calamities, while the consolidation phases indicated steady growth in tourist numbers surpassing the resident population. A well-developed tourist hub helped boost the livelihood of the communities

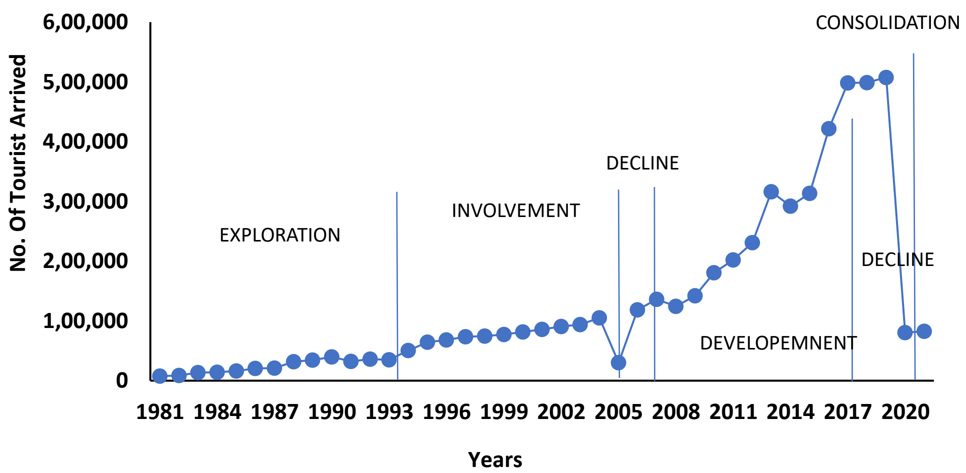


Fig 7.4.1a TALC for domestic tourists

Figure 7.4.1b. represents sequence of stages of foreign tourists, i.e., involvement (1981-2004), development (2006-2013), stagnation (2016-2018), and decline (2019-2021), did not align with the original phases of life cycle. Development stage and stagnation stages were interrupted by a second short decline phase from 2014-2015. The initial decline in 2005 may be attributed to the impact of the Tsunami. Similar to the total tourist arrivals, the post-development phase was again followed by a period of stagnation for 2 years, after which a steady decline began, marking the onset of the COVID-19 pandemic.

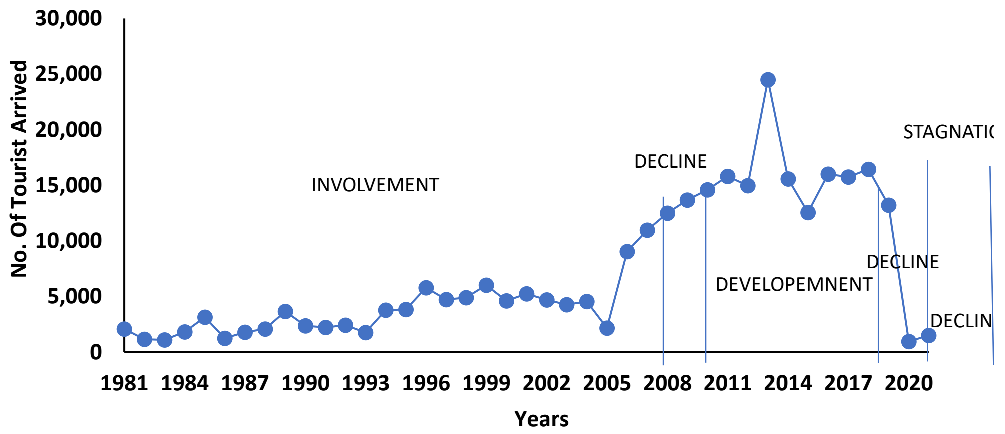


Fig 7.4.1b. TALC for foreign tourists

Total tourists in Figure 7.4.1c showed a leap from the first stage (1981-1993) to the involvement stage (1994-2004), followed by very long period of development (2006-2016), a consolidation phase of (2016-2019) and finally a decline phase of (2020-2021). The tourism industry has experienced rapid growth and development since 1981, bypassing the stagnation phase usually seen between consolidation and decline.

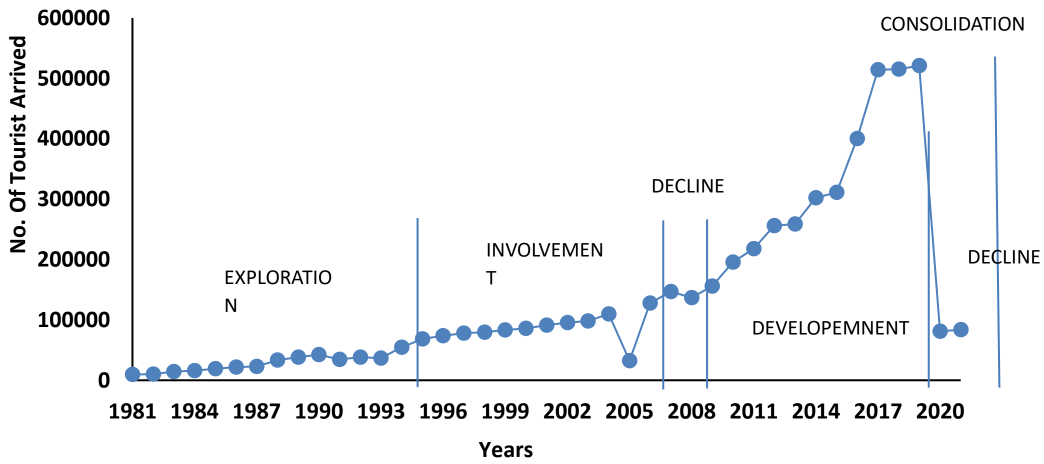


Fig 7.4.1c. TALC for total tourists

After a decade of growth, a decline occurred in 2005 due to a natural catastrophe; however, this decline was short-lived, lasting only a year. Following a growth phase in 2015-2016, the industry entered a four-year consolidation period, which indicates steady growth and development.

7.4.2. Prognosis For the Next Phase of Andaman's Evolution as A Tourist Area

The forecast for Anaman's progress (2021–2061) for time series 1991, 2001, 2011, and 2021 (Table 7.4.2) was verified at coefficient of determination in the polynomial function of total tourists ($R^2 = 0.9961$), number of residents ($R^2 = 0.9805$), and number of hotel beds ($R^2 = 0.9986$).

Table 7.4.2 Trend Function Tourism Evolution in Time Series 2021–2061

Years	No. Of Tourists	No. Of Hotels	Population
1991	34490	32	241453
2001	91115	41	314084
2011	218035	129	343739
2021	520749	337	403000

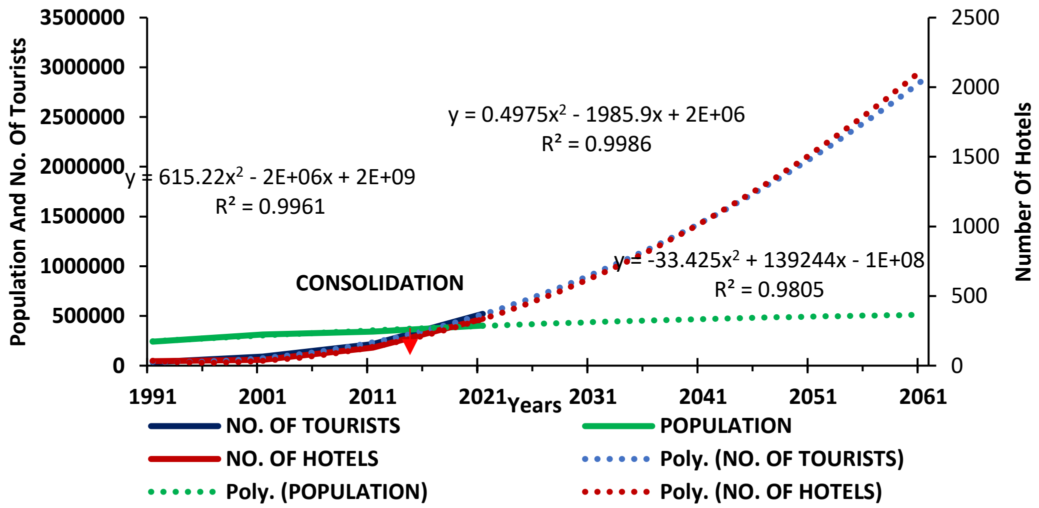


Fig 7.4.2 Prognosis for the next phase of Andaman Island tourism evolution in time series 2021–2061.

In Fig 7.4.2, a trend was observed for tourists and hotels, as well as consistency for the population variable starting from 1991. The trend lines of residents and tourists intersected in 2017, indicating that total tourists and residents shared almost an equal ratio (Fig 7.4.2). This suggests that the tourism development cycle entered the consolidation phase (Butler 1980).

7.4.3 Assessment of the Over Tourism Risk Phenomenon in Andaman Based on The Tourism Intensity Index, Tourism Density Index and Beach Impact Index

Port Blair showed the highest score in Tourist Operation Index (TOI) (4.02%) followed by Rangat (0.71%) and Mayabunder (0.5%) while Diglipur had the lowest score (0.12%). The islands with high to moderate TOI values demonstrated potential for exclusive growth of tourism. In terms of Tourism Density Index (TDI) Port Blair and Mayabunder had significant scores whereas Rangat and Diglipur had the values far less than one (Table 7.4.3). The over-tourism risk at the popular beaches of Andaman Island was classified based on the Beach Impact index (R^2 = 0.9488). Port Blair had the highest population per meter of beach with 172.7, while Mayabunder and Rangat were at medium risk with 66.7 and 64 people per meter of beach, and Diglipur had the lowest with 51.5. The analysis of the impact of over-tourism on Andaman Island beaches from 2011 to 2051 revealed a continuous increase in human pressure, posing a serious threat to beach ecosystems.

Table 7.4.3 Beach Carrying Capacity Assessment of Andaman Beach Tourist Spots

Carrying Capacity Indices	Diglipur	Mayabunder	Rangat	Port Blair
Beach Length in m	839.86	388.88	576.37	998.3
Population	43183	25788	36626	165754
Area	1523.4	857.4	1355.3	548.4
Pop Den	28	30	27	302
Hotel Beds	52	131	261	6173
Beds In Other Accommodation	0	0	0	503
Total Beds	52	131	261	6676
Beds/sq.km	0.034	0.15	0.19	12.17
Seasonal Population	43235	25919	36887	172430
TOI (%)	0.12	0.5	0.71	4.02
TDI	0.00008	0.00059	0.00053	0.00734
BII	51.5	66.7	64	172.7

7.5 Discussion

7.5.1 Analysis of Talc Curve

- **Exploration stage (1981-1993):** In the late 1980s, the increasing number of domestic tourists began to impact the local lifestyle of the Andaman Islands. Over a period of twelve years (1981-1993), the growth rate of domestic tourist arrivals was 79%, compared to 13.9% for foreign tourists. The Indian Government's civil aviation policies favoured tourism in Andaman Islands (EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008). Although domestic tourists outnumbered foreign tourists, they mainly comprised of people of Bengal, Bihar, and Delhi. Domestic tourists tended to prefer organized visits with family and friends to popular destinations, while foreign tourists were more inclined to be independent backpackers (EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008). During this period, tourism solely revolved around nature and culture, specifically concentrated around beaches and Port Blair town. The local government was not involved in monitoring tourism activities as well as amount of tourist inflow was found far below the total population of the island (Fig 7.5.1a). The settler communities living on the coasts benefited socially and economically by hosting foreigners (EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008).

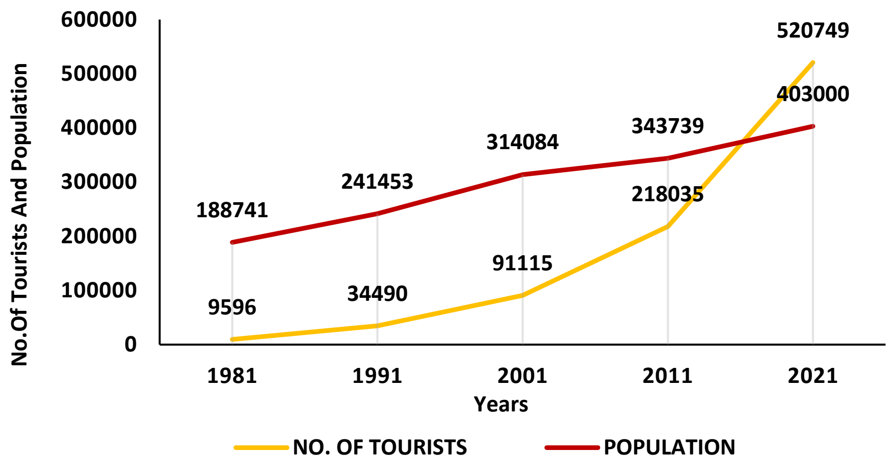


Fig 7.5.1a. Population and Tourist ratio in Exploration stage of TALC

- **Involvement stage (1994-2004, 1981-2004):** The involvement stage was observed for domestic and total tourists from 1994 to 2004, while for foreign tourists, the cycle skipped the exploration stage and started with the involvement phase from 1981 to 2004. No distinct growth pattern in foreign tourist arrivals could be noticed since the inception of tourism in Andaman in 1981, thus, a prominent exploration stage could not be deciphered. The island experiences distinct seasonal patterns in tourist visits, which can be seen by analysing the monthly tourist arrivals (Fig 7.5.1bi and ii). It was observed that domestic tourists prefer to visit from January to March and October to December, while there is a significant increase in foreign tourist arrivals from January to mid-April compared to other times of the year. Between June and December 2006, there was sharp spikes in foreigners, with notably higher numbers than in previous years. They came to the islands in cruise ships. (EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008). The attractions in and around Port Blair were more popular among domestic tourists, while Swaraj Dweep was significantly more popular among outsiders. During this time, many hotels, rest houses, and lodges sprung up and Government proposed to develop cruise tourism in the A&NI (EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008). Such initiatives along with CRZ, 1982, gave the necessary impetus to domestic and foreign tourist arrival in the island destination as evident from the increase in tourist number compared to the previous year (Noronha, 2004) (Fig 7.5.1b iii).

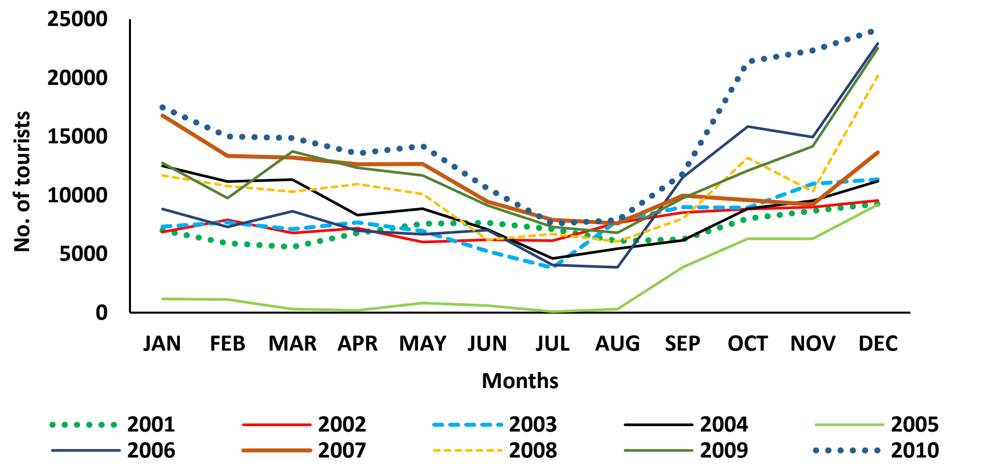


Fig 7.5.1bi. Intra-year Seasonality in Domestic Tourist Arrivals to the Andaman & Nicobar Islands (2001–2010)

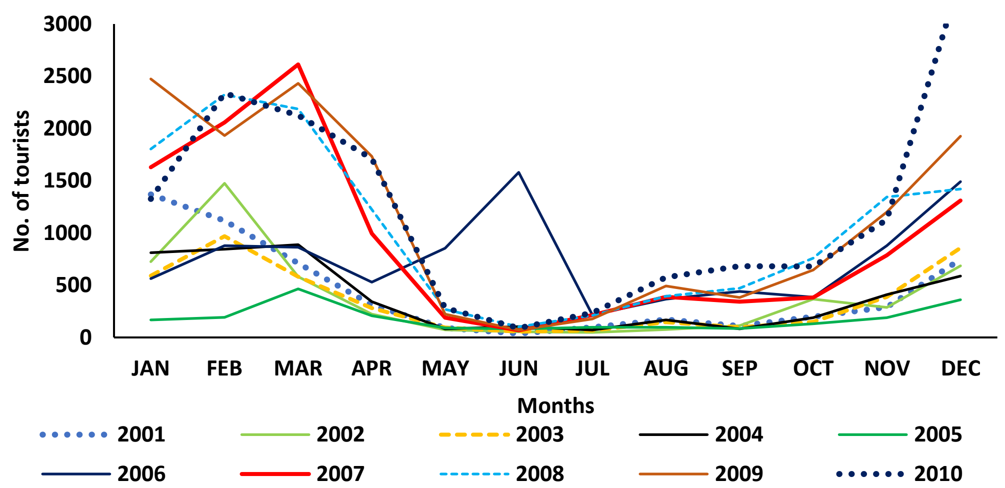


Fig 7.5.1bii. Intra-year Seasonality in Foreign Tourist Arrivals to the Andaman & Nicobar Islands (2001–2010)

Significance of these islands was formally acknowledged in 1997 with the MoTC-WTO (now UNWTO) master plan, which highlighted their potential for tourism promotion.

Additionally, the islands have gained from various administrative schemes aimed at enhancing revenue generation and rural tourism. Several studies focused on tourism in these islands have been commissioned by the Central Government, further emphasizing the importance of this sector (Sharma et al., 2019). Two notable projects funded by the UNDP, with the World Tourism Organization (WTO) and National Environmental Engineering Research Institute (NEERI) have been carried out for highlighting the commitment to sustainable tourism development in the region (Sharma et al., 2019).

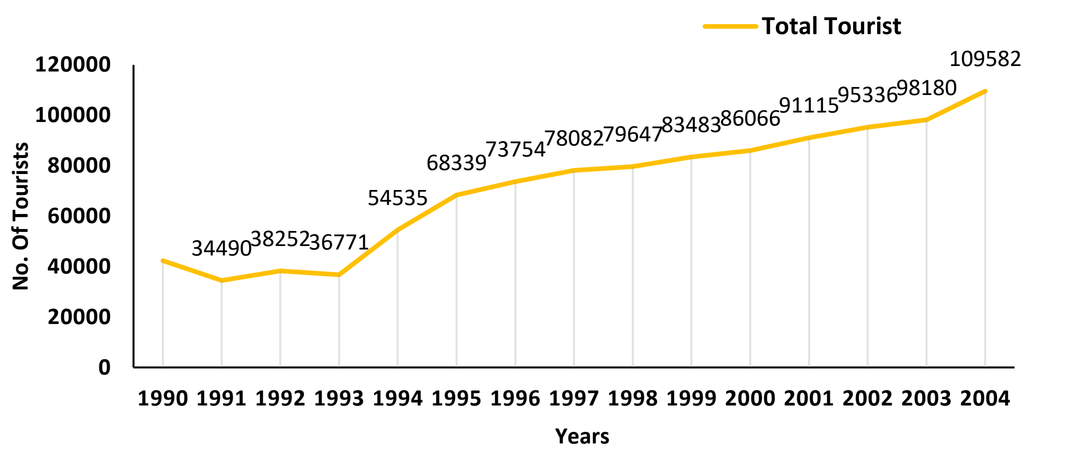


Fig 7.5.1b iii. Increase in the number of tourists in the Involvement stage (1993-2004)

- **Development stage (2006-2015,2006-2013):** The development stage for both domestic and foreign tourists began in 2006, lasting until 2015 for domestic tourists, and until 2013 for foreign tourists (Fig 7.5.1ci). It is essential to recognize the significance of government involvement in planning and providing infrastructural facilities to boost tourism, as it serves as an important indicator in Butler's (1980) stage of development (Berry, 2000).) The popularity of travel agencies and tour operators among domestic tourists has been evident, with many choosing to plan their own travels. However, tour operators in major cities like Delhi and Kolkata have effectively catered to the needs of LTC tourists through organized trips to the Andaman & Nicobar Islands, supported by local agencies. Tsunami prompted the Government of India to issue Memorandum No. 31011/3/2005-Estt. (A) in May 2005, aimed at boosting tourism in the islands (EQUATIONS, INTACH Andaman

& Nicobar Islands Chapter, 2008). This memorandum relaxed Leave Travel Concession (LTC) rules, allowing government employees to use their LTC to visit the islands. Additionally, Group A and B government servants were granted permission to fly to the islands from Kolkata or Chennai. As a result, the islands experienced a significant increase starting in 2006, thanks to enhanced air connectivity and the relaxed regulations, which made air travel more accessible for employees eager to discover the islands (EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008). Initially, two daily flights from Chennai and Kolkata were operated by Indian Airlines. Today, six airlines operate 8334 daily flights, bringing in 1273412 domestic and foreign tourists to the islands daily (Directorate of Economics and Statistics, 2023) (Fig 7.5.1cii).

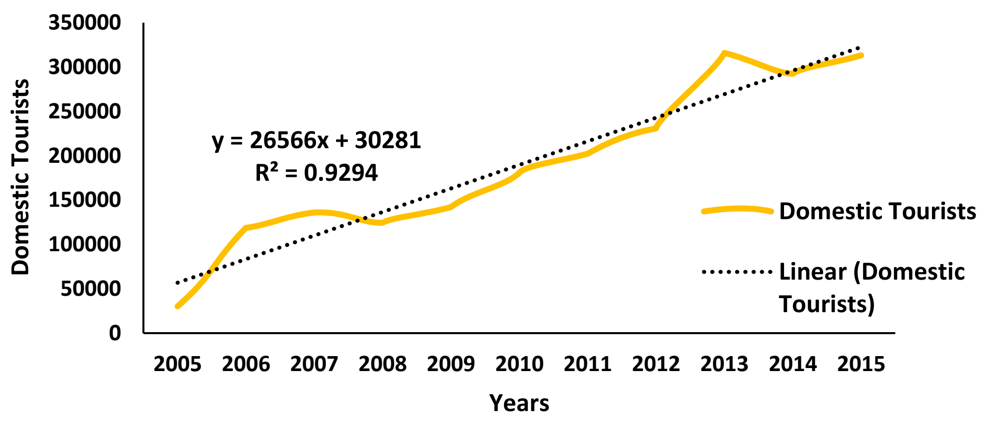


Fig 7.5.1c i. Growth in domestic tourists over the period (2005-2015)

The government's revenue from the tourism sector exhibited a positive growth trajectory until the devastation caused by the tsunami resulted in a substantial decline in earnings, as delineated in Table 7.5.1 c. In response, the government undertook various initiatives aimed at attracting foreign and domestic tourists to the island, culminating in enhanced revenue generation in the aftermath of the tsunami. Such favourable variations in earnings, manifested through tourism developments, could be considered a leading indicator of the island's developmental stage (Directorate of Economics and Statistics, 2014).

Table 7.5.1 c. Revenue earned by the Administration from the Tourism Sector in Andaman Island (Source:Tourism Statistics of India,2016)

Years	Revenue Receipt in Lacs	%Variation In Previous Years
2000-01	79.36	
2001-02	111.38	40.35
2002-03	132.73	19.17
2003-04	137.91	3.90
2004-05	102.35	-25.78
2005-06	66.87	-34.66
2006-07	182.45	172.84
2007-08	189.04	3.61
2008-09	203.63	7.72
2009-10	239.57	17.64
2010-11	248.19	3.64
2011-12	260.81	5.08
2012-13	227.66	-12.7
2013-14	285.69	25.48

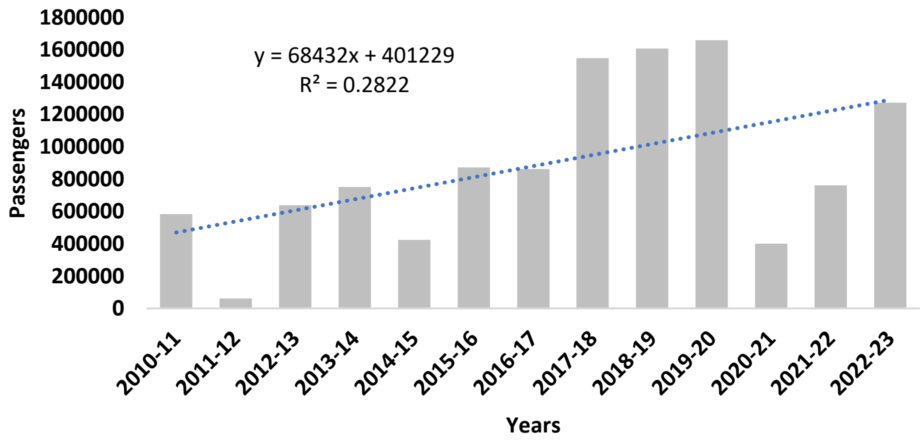


Fig 7.5.1c ii. Growth of Air traffic on the Island over the period (2010-2023)

The establishment of Dolphin Resort in 1994 boosted up the industry on Swaraj Dweep Island in Andaman. The growing popularity of Radhanagar Beach, highlighted by a feature in TIME Asia, increased the number of visitors and resorts.

As the industry started developing, fish, vegetables, and other goods became expensive which caused resentment among locals. Government-owned museums became important man-made attractions, and services like laundry and pharmacies began to appear in various tourist spots, all in compliance with Butler's theory of the development cycle (EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008)

- **Consolidation stage (2016-2019):** The consolidation stages were identified for total and domestic tourists (2016-2019). In 2015, tourism became a major economic activity in the region (ibid). In 2019 Central Government and Niti Ayog launched the "Holistic Development of Identified Islands" initiative, giving high priority to this process. Sixteen islands, including Aves, Long, Little Andaman, Smith and Ross, etc, were selected and given a unique name as a part of the initial "Brand Marketing" effort (Niti Ayog, 2019). The National Tourism Policy of 2020 laid out a comprehensive plan to evaluate and revitalize the "Incredible India" brand in order to better align with the expansion and diversification of India's tourism offerings. It proposed the creation of sub-brands within the Incredible India umbrella to cater to specific sectors such as MICE, Medical Tourism & Wellness, and Adventure Tourism, aiming to bolster India's presence in the global market for these segments. Furthermore, the policy underscored the importance of leveraging advertisements, advertorials, and other promotional methods in both analogue and digital foreign media, as well as magazines, to effectively showcase the rich tourist content of Incredible India in an engaging, inspiring, and informative manner (National Tourism Policy, 2022). In Swaraj Dweep, there is a need to enhance opportunities for residents to actively participate in policies that impact their lives (Sharma et al., 2019). According to Butler (1980), a key factor for entering the consolidation stage is when the total visitor count surpasses that of permanent residents (Berry, 2000). This transition was observed between 2016-2019, coinciding with a decline in the tourist growth rate during this period (Fig 7.5.1d). The decrease in the number of local residents and increasing dissatisfaction with tourism could be lagging indicators of the consolidation stage. However, the development of a prominent tourism business district, effective advertising and marketing strategies to promote island tourism, and the rapid growth of resorts and hotel chains are leading indicators that support the classification of this period as a consolidation stage (Gore et al., 2021). The $200 million infrastructure plan outlined by NITI Aayog and the involvement of prominent hotel groups like Marriott, ITC, Taj, and Oberoi in establishing resorts and other amenities shows promising opportunities for tourism in the region. The focus on enhancing the islands' standing as a diving destination and the efforts to improve infrastructure, including road expansion and bridge construction, will certainly unlock new tourism potential and make the islands more accessible. The removal of thirty small islands from the Restricted Area Permits list also offers visitors the chance to explore the diverse biodiversity of the archipelago. Overall, these initiatives present an ocean of opportunities for the UT.

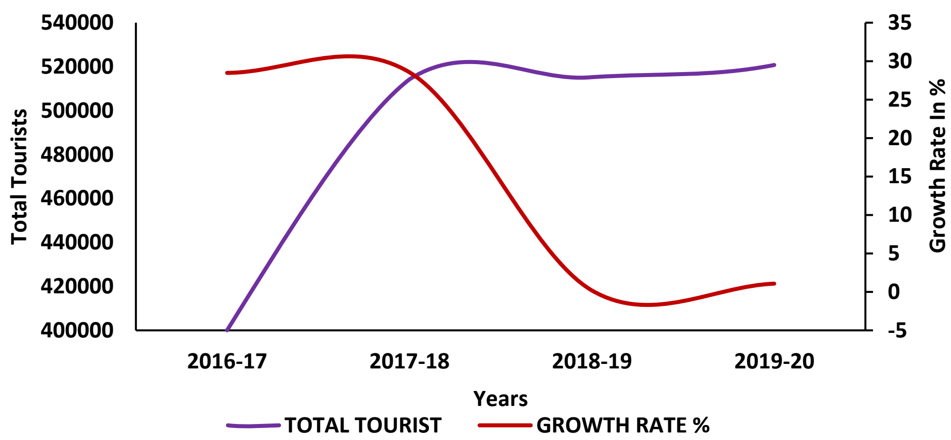


Fig 7.5.1 d. Increase in total tourists and reduction in growth rate of total tourists in Andaman (2016-19)

- **Stagnation stage (2016-2018):** The stagnation stage was only observed among foreign tourists. Even though national tourists agreeably increased from 202,221 to 384,552 in 2011-2016 (Tourism statistics of ANI, 2016), the influx of tourists from outside India remained stagnant. In 2011, it was 15,814; this number increased from fifteen thousand to 17,235 in 2014, but then dropped again to 15,466 in 2016 (Niti Ayog, 2019). The signs of stagnation were evident through various indicators such as repeated visits by foriegn tourists, lack of interest among foreign tourists, development of man-made attractions like water sports parks, increased underwater activities such as snorkeling and scuba diving, heavy tourist traffic in beach areas, and environmental degradation caused by sand extraction for construction and construction of jetties (EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008).

- **Decline stage (2005), (2019-2021):** In 2005, all three categories of tourists—domestic, total, and foreign—experienced a decline due to the devastating December 2004 Tsunami earthquake. This event caused significant loss of tourists in both the sectors. The second decline was marked by the global Covid-19 pandemic, which hit India in 2020 and caused socio-economic devastation in every possible way aside from loss of life. Since the decline was solely due to natural causes, although it significantly hampered tourism growth, it could not be considered a threat, unlike decline mentioned by Butler in his theory.

7.5.2 Prognosis of Andaman's Next Phase of Evolution as a Tourist Area

According to various reports, it was anticipated that tourist traffic to the islands would rise to 134527, 168393, and 243342 by 2007, 2012, and 2022, respectively (Rajavel,1998). Additionally, the population of Andaman Island was projected to increase from 3, 81000 to 402000 during the period from 2011 to 2022, eventually reaching 414000 by the year 2036, according to the Report of the Technical Group on Population Projections (2020).

Upon visually assessing the graph of the 1991, 2001, and 2011 decadal time series (Fig 7.5.2), it was evident that there was an upward trend in development with random fluctuations in the analysed variables. As a result, it was deemed appropriate to use trend function models for the decadal time series to predict tourism trends in the Andaman Islands for 2021–2061. This analysis indicated that the island entered the consolidation phase in 2017, as evidenced by the TALC curve of domestic tourists, and at present is settled in the development phase. Travel industry in the Andamans have reached a critical juncture. Multiple public and private tourism projects are currently underway. Number of tourists was anticipated to reach to nearly 1.2 million by 2020 (NITI Aayog, 2018). Although the actual tourist influx did not exceed one million in 2020, discussions regarding the sustainability of tourism in the region have become imperative for the future. To stimulate the island's economy post-Covid, the government and private enterprises have jointly initiated significant tourism development programs with the aim of promoting sustained economic growth and development for the island in the foreseeable future. It is anticipated that by 2061, the influx of tourists will surpass the local population by two-fold, potentially resulting in overtourism within the region. This scenario closely aligns with Butler's development and consolidation stage. Consequently, it is necessary to promptly undertake measures in the tehsils most vulnerable to this phenomenon (NITI Aayog, 2018).

7.5.3 Assessment of Beach Carrying Capacity of The Island Based On TOI, TDI And BII

The expansion of tourism in coastal areas results in heightened competition for natural resources, including freshwater, space, transportation, and waste disposal. This inevitably leads to conflicts among various stakeholders. It is imperative to precisely delineate the concepts of "development" and "environmental quality" to foster the sustainable utilization of resources. Furthermore, it is crucial to establish robust indicators of quality and sustainability to evaluate and strategize the management of fragile ecosystems such as sandy beaches, which face threats from both land and sea (Fanini et al.,2005). To effectively manage coastal resources and plan for future developments, conducting a tourism-carrying capacity assessment is a valuable approach. In India's coastal zone, the issue of carrying capacity is becoming increasingly urgent due to rapid developmental changes. The island's residents primarily rely on the tourism industry for their livelihoods. As a result, assessing Andaman's Tourism Capacity through specific indicators is crucial. The Tourism Operation Index and Tourism Density Index (Fig 7.5.3a) reveal that overtourism significantly threatens the Port Blair tehsil, which is at the highest risk. Following Port Blair, Rangat and Mayabunder—both situated on the east coast—are also experiencing a high level of tourist activity. Moreover, the Beach Impact Index indicates that Port Blair has a notably high number of tourists per meter of beach, with Mayabunder, Rangat, and Diglipur following in this regard.

The Beach Impact Index is a useful indicator that broadly describes the pressure on the entire coastline of the Andaman Island (Fig 7.5.3b). This index also varies based on the level of tourist activity and the suitability of each beach for visitors. Therefore, in highly popular tourist areas, the beach impact will be high and vice-versa (Vandarakis et al.,2018). Tourist traffic is usually concentrated in popular beach sites such as North

Bay, Chiriyatapu, Corbyn's Cove in Port Blair, Radhangar, Laxmanpur, Bharatpur in Swaraj Dweep and Shaheed Dweep, Baludera, Moricedera in Rangat, Ross and Smith, Pokadera, and Avis in Mayabunder.

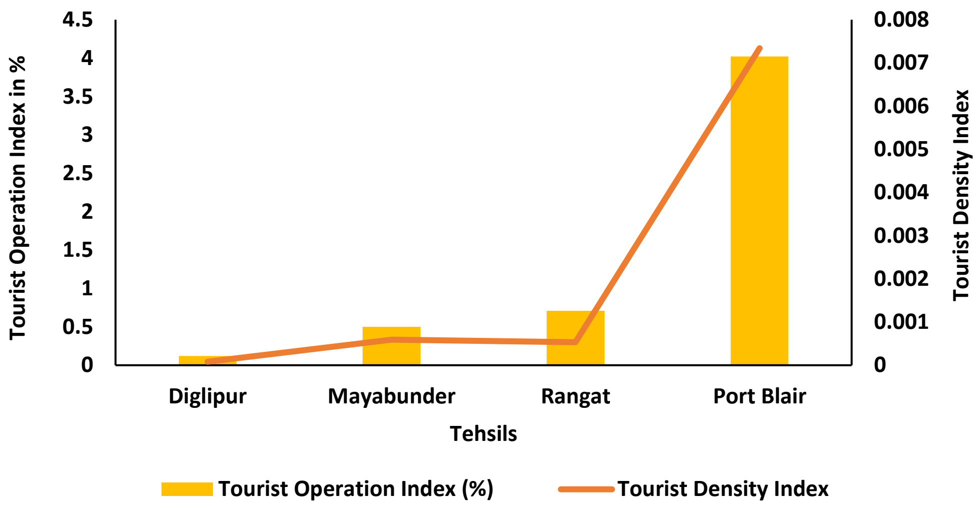


Fig 7.5.3a Tourist Operation Index and Tourist Density Index for famous beach spots of Andaman.

The forecast for the Beach Impact Index of Andaman beaches over the next 40 years indicated increasing tourism pressure, which could be harmful to the beach ecosystems. Various water sports activities focused on the popular beaches of Havelock and Neil, Chiriyatapu, North Bay, Wandoor, Smith, and Ross are putting significant stress on the corals and beach habitat due to the large number of tourists, and this is expected to increase shortly. The current pattern of tourism development in Andaman Island has led to significant tourism growth in the Port Blair tehsil, as indicated by the Tourist Operational Indicator and Tourism Tension Indicator (Lagos & Diakomichalis, 2014; Panoussi & Soklis, 2015). However, due to the non-rational use, negative effects on the environment are evident (Kyriakou et al., 2017).

Modern strategies for promoting and developing tourism must take into account both social and financial dimensions. The goal is to preserve a region's natural resources, along with tourist inflow all the year round (Manzoor, AK, 2015; Kyriakou et al., 2017).

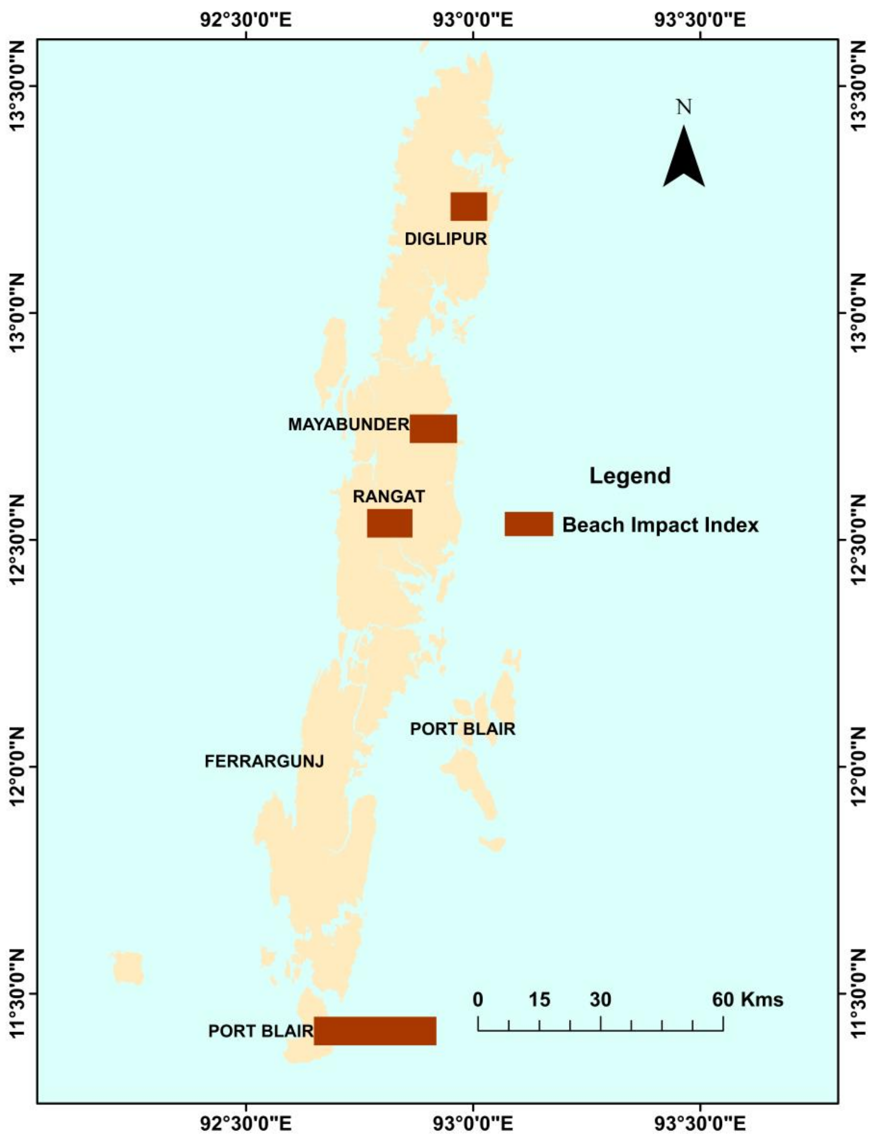


Fig 7.5.3.b Beach Impact Index for popular beaches of Andaman Island

Port Blair boasts a rich cultural heritage and is close to popular beach destinations such as Corbyn's Cove, Chiriyatapu, and Jolly Buoy. Number of hotels, have increased in recent years. While tourists visit attractions and explore other parts of the island, most tend to stay in Port Blair, Swaraj Dweep, and Shaheed Dweep (Niti Aayog, 2019). Swaraj Dweep (Havelock) and Shaheed Dweep, located approximately 39 km and 37 km away from Port Blair respectively are home to the stunning beaches which offers a popular sunset view and attracts sufficient tourists (Niti Ayog,2019). The high volume of tourists in this area have led to various problems such as water stress, excessive waste, and shoreline developments, particularly in Port Blair. These demands adopting sustainable tourism management options. Proposed tourism projects in Aves, Long, Smith, and Ross Islands could potentially limit tourist visits to Swaraj Dweep and Shaheed Dweep, ensuring that the islands can sustainably support tourism (Niti Ayog, 2019).

7.6 Scope of Sustainable Tourism in Andaman Island

It is imperative that earnings from tourism activities are channeled into sustaining existing programs and funding new projects that directly benefit the community (Olowookere et al., 2022). Rural tourism stands out as the most popular option, driven by significant socioeconomic development and the compelling cultural attractions of rural environments. This trend is firmly positioning rural tourism as a top choice for a growing sum of travellers (Simion, 2011). Key characteristics include a close connection to nature, a peaceful atmosphere, and a profound understanding of local culture and communities. Visitors have the chance to engage intimately with local businesses and form meaningful connections with residents and government officials, fostering a sense of belonging during their stay (Olowookere et al., 2022).

Agriculture based-tourism combines nature, accommodations, and farming-related services. This approach supports economic growth of local families by promoting lodging and highlighting regional products (Dinu, 2002). This beneficial relationship between visitors and local communities shows how rural and agro-tourism positively impacts sustainable development (Dinu, 2002; Olowookere et al., 2022

It is critical to preserve the Andaman's cultural and natural heritage while also promoting the islands as ecotourism destinations to attract both domestic and foreign tourists (Ecotourism Policy Guidelines,2015). The Government of India recognized twelve islands to promote marine parks (Bijoor et al.,2018). The management strategy emphasized implementing boundaries using buoys and boundary pillars, as well as managing a buffer zone around the park for tourism and recreational activities (Bijoor et al.,2018). It is recommended that priority be given to reduce excessive beach load of tourists in Port Blair the developing infrastructure, in Mayabunder, Rangat, and

Diglipur. These beaches have relatively low tourist intensity and high beach impact values (Niti Ayog,2019).

7.7 Conclusion

Coastal zones in India offer various services, and tourism is becoming increasingly popular in these areas. However, tourism can significantly impact the environment, society, culture, and economy, making it essential to assess tourism carrying capacity for better management of coastal regions, as noted by Sridhar et al. (2016).

In the Andaman Islands, the tourism development has gone through three phases: exploration before 1960, involvement from 1960 to 1985, and development from 1985 to 2019. By 2017, Andaman reached a consolidation phase where tourists matched the local population, raising concerns about overtourism. While more tourists can boost the economy, it may also harm the island's natural environment and recreational areas. Research indicated a high risk of overtourism in Port Blair and a low risk in Diglipur, based on factors like the number of tourists compared to residents and beach capacity.

By promoting self-sustaining projects, these programs can allocate funding to tourism-related businesses. This approach helps to alleviate poverty and protect both cultural and natural heritage, ultimately benefiting tourists and residents alike (Bansa and Kumar, 2021). It’s also important to focus on environmental preservation and sustainable development in the islands. Educational programs and museums can help raise awareness about issues like climate change and habitat loss among visitors. By encouraging responsible behaviors, these initiatives can foster a shared commitment to sustainability, helping to protect resources for future generations (Cole, 2017).

CHAPTER-8

GENERAL DISCUSSIONS AND RECOMMENDATIONS

The title of the thesis is "Vulnerability Assessment of Mangroves and Corals to Climate Change and its impact in Andaman Islands". The research delves into the vital role that corals and mangroves play as two of the some of the most fecund systems on Earth. Unfortunately, these ecosystems, particularly in the tropics and subtropics, face significant degradation due to unpredictable climatic conditions and harmful human activities. The Andaman Islands are a prime example of it. Unsustainable logging, urban encroachment, pollution, coastal development, and agricultural conversion are leading to serious harm. Furthermore, climate-related exacerbate these challenges, disturbing the fragile balance of these ecosystems.

In light of the extensive degradation observed, the thesis tried to estimate the current status these ecosystems have, evaluate their economic benefits, and seeks to explore how environmental changes may impact these services. The research culminates in the formulation of probable adaptation strategies to manage the degradation of these vital ecosystems. Key findings are outlined in the respective chapters. Chapter 4 presents a biophysical vulnerability assessment, gauging the conditions of coral -mangrove ecosystems and evaluating the effects of climate change stressors. Chapter 5 examines the social vulnerability of communities in the Andaman Islands, identifying those most susceptible to environmental hazards related to climate change. Chapter 6 focuses on how coral vulnerability affects fisheries in the region, while Chapter 7 analyzes the status of tourism, emphasizing its role in sustainable development. Results from these chapters are synthesized to inform and support the thesis's objectives, leading to the identification of potential management solutions.

Investigation into the vulnerability of the mangroves and corals of Andaman Island highlights critical environmental challenges and underscores the use of the IPCC's conceptual framework for vulnerability assessments. The findings reveal significant variations in vulnerability across the island's tehsils, with Mayabunder showing the highest vulnerability due to its exposure to various environmental stressors and its sensitivity to changing conditions. In contrast, areas like Ferragunge and Port Blair demonstrate considerable adaptive capacities, evidenced by the successful regeneration of mangroves and the expansion of new mudflats, indicating resilience in the face of environmental changes. Moreover, the unique properties of Andaman's mangroves contribute to their status as some of the best in India. The presence of undisturbed hydrological regimes, adequate sediment supply, and proximity to healthy mangrove populations create ideal conditions for growth and recovery. However, the study points out that certain regions, particularly small islands or areas at lower elevations, remain highly susceptible to threats of ocean surge.

Post-tsunami regeneration efforts have shown promise, yet ongoing threats such as tidal invasion and habitat loss due to deforestation for socio-economic development pose significant risks. This complexity calls for integrated management tactics to protect these crucial ecosystems for future generations. Overall, the research thrusts on adaptive management to mitigate vulnerabilities and sustain the health of Andaman's invaluable mangrove and coral ecosystems.

The mangroves of North Andaman are at a higher risk compared to those in South Andaman due to several factors, including lower species richness, logging, agricultural expansion, and a slow self-regeneration potential. These mangroves are vital for the ecological health providing direct benefits that are reaped by local communities such as fishermen, farmers, laborers, and sectors like pharmaceuticals and tourism. They also contribute to indirect benefits including biodiversity conservation and shoreline protection. Reefsof Andaman Islands were destroyed by seismic events and tsunamis, notably during the 2004 earthquake, which caused significant geological changes affecting reef and mangrove areas. While the North Andaman experienced a substantial loss of coral cover (30%), South Andaman faced a comparatively lower loss (20%). The reefs have faced multiple bleaching events from 1998 to 2015, with severe impacts noted in certain areas. Despite a low population density, rising tourism and related development activities have introduced anthropogenic threats to these ecosystems, contributing to coral degradation.

Small island territories, including the Andaman Islands, are exceedingly vulnerable to modified climate and this weakness is further compounded by socio-economic factors that affect the islanders' livelihoods, highlighting the need for a thorough spatial analysis based on the IPCC AR4 framework. Adaptation power of the people of Andaman plays a decisive part in mitigating this vulnerability. However, this capacity hinges on several key elements: the adoption of appropriate technologies, access to requisite resources, and a high level of societal awareness. Despite a significant number of islanders receiving education, many still engage in traditional occupations such as agriculture, fisheries, and animal rearing. The Indian Government's post-independence policies facilitated increased migration to the Andaman Islands, further complicating the socio-economic landscape. This population surge, particularly from refugees in Bangladesh, has led to dramatic demographic changes, primarily in the north sectors.

Study underscores that while initiatives for adaptation, such as religious efforts and systematic planning, are beneficial, they must be coupled with ongoing assessment and vigilance against persistent climate threats like rising sea levels, cyclones, and flooding. The socio-economic vulnerability is notably higher in the northern part of Andaman, which faces significant threats to its biodiversity—critical for the ecosystem services essential to the islanders' livelihoods. For instance, Diglipur, with its predominantly rural population engaged in agriculture, is especially at risk from natural hazards compared to more urbanized areas like Port Blair. Furthermore, critical issues such as limited water resources, inadequate medical facilities, and poor sanitation conditions in areas like Rangat and Ferrargunj exacerbate the vulnerabilities faced by coastal communities. Therefore, addressing these challenges is imperative to safeguard the livelihoods and well-being of the Andaman islanders.

The developmental policies implemented by the government have undeniably played a role in the destruction of the forest ecosystem, particularly due to the extensive clearing of land for industrial purposes in the southern regions. The construction of the Kalpong hydroelectric power station serves as a prime example of it Additionally, the government's proposals to expand the road network from South to North Andaman, along with plans to widen existing roads and construct new government buildings, are expected to exacerbate deforestation. Such an expanded network facilitates increased human access to the forest, ultimately leading to greater exploitation of its resources.

In terms of marine ecology, a reliable climate model has been adopted for the Andaman Region to better predict future coral bleaching events, allowing for better planning of coastal and marine fisheries activities and the creation of risk-reduction strategies to mitigate the effects of environmental changes on the reef fisheries of Andaman Island. Findings indicate that, sea surface temperature projections are on an upward trajectory throughout the 2030s, 2050s, and 2060s, which correlates with an expected recurrence of bleaching during these years. Notably, previous coral bleaching incidents, such as the one in 2016, had a significant negative impact on fish catches in Andaman, particularly among perch species. Despite these challenges, fish stock exploitation has seen a steady rise from 31,058 to 39,284 metric tonnes between the years 2003–04 and 2017–2018.

Moreover, the maritime fishery in Bay Isles is grappling with major challenges, many of which surpass those posed by climate change. These challenges include a absence of comprehensive data on stock, illegal poaching, inadequate logistical support for operations. The expansion of industrial fishing is further hindered via insufficient infrastructure and skilled labour. Fishing efforts predominantly focus on coastal areas reliant on coral reefs, while vast offshore and deep-sea regions remain largely untapped due to traditional, non-mechanized fishing practices and limited understanding of the lucrative deep-sea resources available. Currently, marine fish stocks in the islands only represent 19% of the total potential resources, yielding a production of around 30,000 tonnes. Efforts to manage coral reef fisheries have primarily involved restricting fishers' access to economically valuable marine resources, including edible invertebrates, fish species, ornamental fish, and decorative shells catered to the tourist market.

The tourism sector undeniably places immense pressure on our environment, driving the need for land expansion for hotels and housing, which results in significant declines in environmental functions and increases in pollution and waste. The consequences are severe, including contamination and seawater intrusion into critical aquifers and surface water. Activities such as diving, snorkelling, and swimming threaten coral reef ecosystems, decreasing live coral coverage and impairing their vital functions. In the Port Blair tehsil of Andaman, the impact of tourism has progressed through distinct phases, as outlined by the TALC model. Since entering the consolidation phase in 2017, the balance between the visitors and inhabitants has intensified overtourism. Current analyses reveal a high risk of over-tourism in Port Blair, contrasting with a lower risk in Diglipur, reflecting the urgent need to manage beach tourism capacity.

The ecological resilience of mangroves and corals in South Andaman pales in comparison to their northern counterparts due to ongoing tourist pressure. This situation is exacerbated by infrastructural developments, high population density, and urban sprawl, which jeopardize the ecological diversity of these sensitive areas. The long-term ramifications of climate change coupled with chronic coastal degradation will have dire consequences for local economies. The likelihood of coastal flooding, deteriorating water quality, and food production declines will only deepen food scarcity, posing significant challenges for small island nations that depend heavily on food imports. Moreover, these pressures threaten to trigger unprecedented ecological collapse, public health crises, and severe risks to food security.

Comprehensive climate change strategies must be finalized urgently, considering the economic and livelihood implications of all potential alternatives to safeguard the future of these vulnerable island nations.

Adaptation Options

The enhancement of operation is pivotal for significantly reducing the vulnerability of mangroves and broader ecosystems, a thing attainable through well-funded systems (Ellison and Zouh, 2012). Community mindfulness and educational programs that punctuate the critical part of threat decrease for different organisms and vital for empowering islet communities and bridling the unsustainable exploitation of reserves (Jupiter, 2014). While factors similar as tidal range, relative ocean position rise, can be told by point location and terrain (Ellison, 2015) still, visionary adaption conduct can effectively alleviate pitfalls, allowing directors to enhance the factors of perceptivity and rigidity (Crameri and Ellison, 2022).

Likewise, the health and adaptability of conterminous coral reef ecosystems are non-negotiable for the well- being of mangroves, as these reefs play a critical part in furnishing necessary deposition for mangrove accretion. Growing frequency of coral undergoing pigment loss, aggravated by rising marine heat stress presents a redoubtable challenge, with many options for mitigation (Sully et al., 2019). Nonetheless, guarding crucial species associated with coral reef health, alongside managing nutrient and deposition runoff, is pivotal for prostrating these challenges (ibid). Safeguarding corals is essential for maintaining the well-being of mangroves, given the ecosystem services they give (Moberg and Folke, 1999).

To fight the awaited negativities on mangrove territories, decisive conduct must be taken to enhance the ecosystems' capacity to repel and recover from climate- related stressors (Spittlehouse and Stewart,2003; Turner et al., 2003; Julius et al.,2008).

- Managed retreat- This visionary approach enables careful planning with ample lead time, allowing for operation measures that are economically feasible, socially respectable, and environmentally sound (Titus, 1991). Zoning regulations can be established to produce buffers behind being mangroves, conserving space for the development of unborn mangrove territories. directors can determine the necessary buffer sizes by assessing the rate at which mangroves are moving inland. Grounded on this anticipated landward movement and the anticipated lifetime of littoral developments, applicable construction regulations can be developed (Mullane and Suzuki, 1997).
- Protected area networks play a pivotal part in the conservation of mangrove ecosystems. By establishing and effectively managing these areas, we can enhance the representation of different mangrove community types. This approach not only ensures that we've a range of territories to support the adaptability of these ecosystems but also facilitates the replication of identical communities, which is essential for spreading threat (Julius and West, 2007). The validation is clear when we cover mature and healthy mangrove spots along plages, we significantly boost the chances of natural waterborne seedlings helping to re-colonize degraded areas also, the recuperation of mangrove territories is imperative for their survival (Mumby et al., 2004). By addressing the underpinning issues that have led to the decline of these vital ecosystems, we can strengthen their adaptability.
- Mangrove rehabilitation- Restoration of areas where mangroves preliminarily thrived can act as a countermeasure against the implicit losses brought about by environmental changes. The time to act is now; with combined sweats in establishing defended areas and rehabilitating mangrove territories, we can insure the future of these inestimable ecosystems (Bosire et al., 2008).

To effectively combat the global decline of coral reefs, we must fleetly transition from outdated operation ways to a comprehensive strategy that enhances the adaptability of both coral ecosystems and the communities reliant on them. This system acknowledges the intricate connections within social- ecological systems, as stressed by expert like Bellwood et al. (2004)

- Feting the diversity of coral reefs is pivotal; different species and functional groups play varying places in recovery. Prioritizing operation conduct requires in- depth exploration to identify and cover these vital factors. Indeed, in the absence of specific data, general guidelines fastening on crucial carnivorous groups can bolster reef adaptability (Green and Bellwood, 2009).

- The significance of connectivity in enhancing reef adaptability cannot be overstated. It facilitates the movement of coral larvae, thereby improving recovery opportunities (Jordan F etal.,2003; Hock et al., 2017). Furthermore, the connections between reefs-seagrass-mangrove ecosystems boost organism diversity, which is crucial for recuperation (Mumby and Hastings, 2008)
- Marine Protected Areas (MPAs) play a significant role in increasing ecosystem adaptability by addressing harmful fishing practices, reducing overfishing, and reinstating coral reef food webs (Bellwood et al., 2004). The potential of MPAs to manage coral predator outbreaks and enhance herbivory is vital for coral recovery (Mumby et al., 2007; Selig and Bruno, 2010). Evidence supports their effectiveness in curbing coral loss (Mellin et al., 2016; Wolff et al., 2018) and aiding recovery efforts (Micheli et al., 2012; Perry et al., 2015). However, while MPAs are crucial, they are not a silver bullet against the challenges posed by climate change (Côté and Darling, 2010; Selig and Bruno, 2010; Roberts et al., 2017).
- The success of conservation efforts hinges on the resilience of both ecosystems and human communities (Cinner et al., 2013). Strategies that enhance social adaptive capacity within the Reef Grounded approach are vesting localities to adapt or recover from these conditions-thus fostering resilience. Additionally supporting the fishing and tourism sectors in navigating various challenges and uncertainties, promoting economic diversity, providing alternative livelihoods, strengthening social networks among reef users, and valuing traditional knowledge are critical steps toward a more sustainable future for reef management (Marshall and Marshall, 2007; Seixas, 2008; Cinner et al., 2012).

In the islets adaptive capacity remains vital for local governments, sectoral institutions, agencies, and indigenous communities to effectively confront the risks while embracing new opportunities. Establishing a robust forecasting system for extreme weather events is essential, ensuring that this information reaches grassroots levels. ANIAPCC is structured around several state missions that acknowledge the vulnerability of local ecosystems.:

- Focused coastal ecosystem management through mangrove afforestation in tsunami-affected areas and planting multi-purpose trees in elevated are
- Mission on Sustaining Island Ecosystems and proper use of energy resources- promoting energy-efficient lighting solutions such as CFLs and LEDs, and conducts energy audits
- Sustainable Water Mission: Aims to enhance groundwater recharge, implement rainwater harvesting, and improve existing water bodies through desilting and embankment upgrades.
- Green India Mission: Proposes the protection and enhancement of existing forests, including the transformation of monoculture plantations into diverse secondary forests.
- Mission on Sustainable Agriculture: Involves research focused on climate-resilient agricultural practices and extends sustainable habitat initiatives.

Valuable fishery resources, particularly tunas largely remain exploited in this island state. However, local exploitation is alarmingly minimal, leaving a vast portion of these oceanic resources untapped. This situation represents a significant opportunity for robust economic development through effectively managed fisheries and the promotion of fisheries tourism (Nithyanandan, R. 2009). The successful implementation of "fishing beyond the reef" strategies in Lakshadweep has led to a marked improvement in local fish catches and should undeniably serve as a model for the Andaman Islands. Currently, the lack of mechanized fishing limits motorized crafts to nearshore waters. While tuna stocks have steadily increased, the overall exploitation remains drastically below potential levels. The Andaman Fishery Policy 2018 has taken the critical step of initiating mechanized fishing beyond six nautical miles, supported by research indicating that environmental conditions, such as mesoscale eddies, significantly boost fish productivity (Arur et al.,2014). By harnessing satellite data to identify potential fishing zones (PFZs), harvestable fish catches in the Andaman waters can be augmented considerably. The implementation of these strategies is essential for guiding the region toward sustainable development and meaningful economic growth (George et al.,2011).

Furthermore, the fishing industry's exploitation of juvenile fish has severely compromised global fish populations. The use of nets with improper mesh sizes, capturing numerous young fish, must be tackled immediately. Establishing a minimum legal size (MLS) is not just beneficial; it is essential. This measure defines the smallest size at which a species can be legally retained, protecting juvenile fish and ensuring sustainable spawning stocks for future generations (Takar and Gurjar 2020). By prioritizing the capture of larger fish and maintaining appropriate stock sizes, we can effectively achieve sustainability in fish populations. This strategy squarely addresses two critical issues in fisheries management: growth overfishing and recruitment overfishing (Takar and Gurjar 2020).

Moreover, certification concerning the place, time, method of fish catch, and the quality of the catch has become non-negotiable for effective fisheries management (Potts and Haward, 2007). To counter illegal, unreported, and unregulated fishing, initiatives such as 'Eco-labelling and certification' are essential in the seafood trade, ensuring adherence to sustainable harvesting practices (Macfadyen and Huntington;2007; Ramachandran and Parappurathu,2020).

The most significant barrier to tourism growth (ANI) entails inadequate connectivity and reliable transportation infrastructure. It is imperative that investments in transportation infrastructure align with the priorities and needs of the local population. Given the limited availability of land and the necessity to protect the delicate ecosystem, there must be a stronger emphasis on developing water-based transportation systems. The existing airstrips in Diglipur and Campbell Bay should be utilized more efficiently to facilitate better tourist access from the mainland (EQUATIONS, INTACH Andaman & Nicobar Islands Chapter, 2008).

The Tourism Policy – 2015 of the Union Territory has been designed to drive sustainable tourism that directly benefits local communities by creating jobs and boosting economic growth while ensuring ecological integrity. Key objectives of this policy include promoting eco-tourism to protect fragile ecosystems, leveraging unique scuba diving sites, projecting a tourist-friendly image, enhancing visitor expenditure, focusing on international tourism through regional connectivity, developing high-quality infrastructure, selecting 5-6 islands for targeted development, nominating potential World Heritage Sites under the natural heritage category, and promoting traditional artisans (Niti Ayog, 2019). The planned tourism projects in Aves, Long, Smith, and Ross Islands are crucial for managing tourist numbers and conserving the islands' ecosystems. The predominant demographic of tourists flocking to the Andaman Islands consists of nature enthusiasts drawn to adventure activities such as trekking, camping, and scuba diving, as well as culture, heritage, and bird-watching. While tourists undoubtedly appreciate the islands' natural beauty, it's imperative to recognize that eco-conscious tourists do not always represent the highest economic value. Understanding that eco-tourism attracts individuals with a smaller environmental footprint is essential for effective tourism management

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