Tamil Nadu Climate Change Mission

CLIMATE RISK ASSESSMENT AND ADAPTATION PLAN OF TAMIL NADU

COASTAL ECOSYSTEM

Under

CLIMATE STUDIO

REPORT

2024

Supported by
Department of Environment and Climate Change
Government of Tamil Nadu

Prepared by
Centre for Climate Change and Disaster Management
Department of Civil Engineering
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PREFACE

Climate change has emerged as one of the most significant global challenges of our time, exerting a profound impact on ecosystems, human societies, and economies. Coastal regions in particular, face a growing array of threats from rising sea levels, extreme weather events and coastal erosion, which endanger both the environment and the communities dependent on these fragile ecosystems. The coastal state of Tamil Nadu, with its expansive 1076 km coastline is especially vulnerable, placing coastal resilience and sustainability at the forefront of the policy agenda.

This report is a crucial step toward understanding and addressing the multifaceted challenges that climate change poses to Tamil Nadu coastal zones. It consolidates scientific data, socio-economic insights and climate projections to offer a comprehensive analysis of the current vulnerabilities and future risks. More importantly, it emphasizes the need for actionable adaptation and mitigation strategies to protect the state rich marine resources and the livelihoods of its coastal communities.

This report reflects the collaborative efforts of various experts, government departments and institutions committed to addressing the climate crisis in coastal sector. By providing valuable data and evidence-based recommendations, this report not only informs policy decisions but also serves as a roadmap for sustainable development in the face of climate uncertainties.

We hope that the insights and recommendations within will be instrumental in shaping Tamil Nadu climate resilience initiatives, helping to safeguard both its environment and people for generations to come.

(P.Senthilkumar)

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FOREWORD

Climate change is predominantly attributed by human activities, particularly the release of greenhouse gases like carbon dioxide, methane, and nitrous oxide. In the face of rapidly accelerating climate change, coastal environments are increasingly under threat from rising sea levels, extreme waves, cyclones and coastal flooding.

The coastal zones of Tamil Nadu rich in diverse marine resources are particularly vulnerable to climate-induced impacts, necessitating immediate action. As global temperatures rise, the urgency to protect these valuable coastal ecosystems and habitats is grown. Adaptation and mitigation strategies are important to safeguarding the livelihoods and well-being of coastal communities.

Tamil Nadu has a long coastline of 1076 km and hence, the impact of sea-level rise is a matter of concern to policy makers. This book will be a valuable source material since it contains important data and hence will become a reference material in future. The Tamil Nadu government is committed to protecting the environment and making sure development is sustainable. The Climate Studio at Anna University's Centre for Climate Change and Disaster Management (CCCDM) brings together experts and the community to find solutions. This report helps us plan ahead and protect our communities and environment from climate change.

I am extremely thankful to Dr.P.Senthilkumar, I.A.S., Principal Secretary to the Government, Environment, Climate Change and Forests Department for his valuable guidance and unwavering support in the successful operationalization of the Climate Studio.

I appreciate the efforts of Dr. Kurian Joseph, Professor & Director, Centre for Climate Change and Disaster Management, Dr. A. Ramachandran, Emeritus Professor, Centre for Climate Change and Disaster Management and research team of Climate Studio for collecting, collating and analyzing scientific information from various sectors and compiling the report in the present form.

I would like to extend my appreciation to all the Government line Departments and Institutions for their valuable contributions by providing essential data and information, which played a crucial role in the successful operationalization of the Climate Studio project.

(A.R. Rahul Nadh)

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ACKNOWLEDGMENT

We sincerely acknowledge the support and encouragement by Dr. P. Senthilkumar, I.A.S., Principal Secretary to the Government, Environment, Climate Change and Forests Department. We express our sincere gratitude to Tmt. Supriya Sahu IAS., former Additional Chief Secretary to Government, Department of Environment, Climate Change and Forests, Government of Tamil Nadu, Thiru. A.R. Rahul Nadh IAS., Director, Department of Environment and Climate Change, Government of Tamil Nadu and Thiru. Deepak Bilgi IFS., Chief Mission Director, Tamil Nadu Coastal Restoration Mission, for the successful execution of the project "Operationalisation of Climate Studio" and in completion of the Climate Risk Assessment and Adaptation Plan for the key sectors of Tamil Nadu.

We humbly acknowledge Prof. Dr. R. Velraj, the former Honourable Vice Chancellor, Anna University, Prof. Dr. K.P. Jaya, Head of the Department, Department of Civil Engineering, Dr. K. Palanivelu, Professor, CCCDM, Dr. R. Saravanan, Professor and Director, CWR and the adjunct faculty of CCCDM, Anna University for their valuable inputs and expertise. Further, we acknowledge the support from the following departments for providing the necessary data for the completion of the Climate Risk Assessment and Adaptation Plan for the key sectors of Tamil Nadu:

- Department of Environment, Climate Change and Forests (DoE&CC), Government of Tamil Nadu
- Indian Meteorological Department (IMD), Ministry of Earth Sciences, Government of India
- Central Ground Water Board (CGWB), SECR, Ministry of Jal Shakthi, Department of Water Resources, River Development and Ganga Rejuvenation, Government of India
- State Planning Commission (SPC), Government of Tamil Nadu
- Tamil Nadu Agricultural University (TNAU)
- Department of Agriculture, Government of Tamil Nadu
- Department of Animal Husbandry, Government of Tamil Nadu
- Department of Fisheries and Fishermen Welfare, Government of Tamil Nadu
- Department of Statistics and Economics, Government of Tamil Nadu
- Department of Water Resources, Government of Tamil Nadu
- National Centre for Coastal Research (NCCR), Government of India
- Tamil Nadu Pollution Control Board (TNPCB), Government of Tamil Nadu
- Institute of Water Studies (IWS), Tharamani
- Institute of Remote Sensing (IRS), Anna University

We sincerely thank other project staff and administrative staff of CCCDM for their continuous support towards the successful execution of the project.

Executive Summary

Coastal systems and low-lying areas will face increased threats such as submergence, flooding, and erosion due to sea level rise. Acidification and warming of coastal waters will harm ecosystems. The population and resources at risk in coastal areas will grow due to urbanization and development. Climate change raises the risk of flooding in densely populated coastal zones, endangering people and property. Fair decision-making on coastal adaptation is crucial for supporting UN's Sustainable Development Goals. There are predominantly positive synergies between adaptation options for Life Below Water (SDG14), Climate Action (SDG13), and social, economic, and governance SDGs, shows the potential of coastal adaptation to contribute to overall sustainable development.

The ocean plays a key role in regulating climate by absorbing heat and CO_2, which helps mitigate atmospheric warming, but also leads to ocean warming and rising sea levels from land ice melt. The absorption of CO_2 causes acidification, all of which harm marine ecosystems and dependent communities. The rate of sea level rise has more than doubled since 1993, increased 2.13 mm·yr-1 (1993-2002), 4.77 mm/yr (2014-2023), highlighting the urgent need to address these interconnected challenges.

Sea-level rise in the North Indian Ocean increased from 1.06–1.75 mm/yr (1874–2004) to 3.3 mm/yr (1993–2017), aligning with global trends. By the end of the twenty-first century, NIO sea level is projected to rise by around 300 mm compared to the average from 1986–2005 under RCP4.5 scenarios. While tropical cyclone frequency has increased since the mid-twentieth century (1951–2018) in the NIO basin, the occurrence of very severe cyclonic storms during the post-monsoon season has notably increased by approximately one event per decade over the last two decades (2000–2018).

Climate Studio at CCCDM

Embracing its commitment to the Nationally Determined Contribution (NDC), Tamil Nadu has emerged as a pioneer in developing adaptation strategies across sectors. Utilising the acclaimed IPCC framework on "Climate Change Risk Assessment," the Government of Tamil Nadu has established the 'Climate Studio' at the Centre for Climate Change and Disaster Management (CCCDM), Department of Civil Engineering, Anna University. This state-of-theart facility, funded with Rs. 3.80 crores is equipped with high-performance computational resources and digital learning tools (financially supported by GIZ, Germany) to analyse global climate data at the cadastral level. The Climate Studio aims to provide updated high-resolution regional climate scenarios, assess climate change impacts on natural resources, develop multi-sectoral spatial information, and disseminate knowledge to stakeholders. Through capacity-building programs and workshops, over 250 sectoral officials and thousands of participants have been trained and sensitized, fostering a climate-resilient future for Tamil Nadu.

Coastal Risk Assessment

The coastal risk assessment for the base period – (1992 – 2022) and the near century (2023 – 2050) was assessed using the components of coastal hazards, vulnerability, and exposure. The assessment of coastal hazards, vulnerability, and exposure along the Tamil Nadu Coastline has been determined by analyzing and integrating key indicators. The coastal areas of Tamil Nadu are highly vulnerable to various climate-related hazards such as sea level rise, cyclones, and shoreline changes.

The projected sea level rise of Tamil Nadu for 2050 under the SSP2-4.5 scenario indicates an average increase of 19.71 cm, with Tiruvarur, Nagapatiinam, and Thanjavur districts being the most affected.

It is observed that 59 cyclones made land fall in Tamil Nadu out of which 33 are severe cyclonic stroms (SCS). The frequency of severe cyclonic storms has shown a significant increase in the post-monsoon season, with the number of events occurring at two-year intervals since 2016.

Analysis of shoreline change rates over the past 30 years shows that 36% of the coast has experienced erosion, while 30% has experienced accretion, and 34 % is stable.

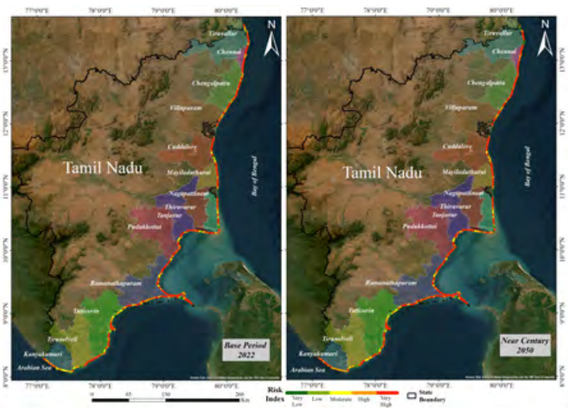
Nagapattinam, Chengalpattu, and other districts are highly susceptible to coastal hazards based on factors such as sea level rise, cyclones, and shoreline change rate. Tiruvarur, Nagapattinam, and Chengalpattu have extensive coastlines with high vulnerability due to salinity levels and low elevation areas. Districts like Kanyakumari, Chennai, and Cuddalore have over 60% of their coastlines exposed to climate change, influenced by factors like land use and infrastructure. High to very high coastal risk projected in Tiruvarur, Nagapattinam, Chennai, Tiruvallur, Cuddalore, and Chengalpattu, with the majority of their coastlines falling into these high risk categories base period and near century. The integration of hazards, vulnerability, and exposure allows for a comprehensive coastal risk assessment, providing valuable insights for stakeholders to adapt and mitigate the impacts of climate change on the Tamil Nadu coast. Overall, the study highlight the urgent need for coastal management strategies and adaptation measures to address the increasing risks posed by climate change on the vulnerable coastal areas of Tamil Nadu.

Coastal Adaptation Actions

The coastal adaptations actions are broadly categorized to address the risk of Sea Level Rise, Shoreline Change and Tropical Cyclones,

- Coastal Livelihood Management
- Hard Measures
- Nature Based Solutions
- Soft Measures
- Technology

The coastal area of the Tamil Nadu is well occupied by the Major Coastal Blue carbon ecosystems such as Mangroves, Coral reefs, Sea grass and Salt Marshes. The districts which are more vulnerable due to Erosion, it is recommended soft measures, living shoreline and Nature based solutions such as conservation and restoration Mangroves, Coastal Plantations, Sandunes, salt marshes etc. plays the pivotal role in mitigating climate change impacts. The districts which are more vulnerable due to Sea Level Rise induced inundation under SSP2-4.5 Scenario, it is recommended Nature-based solutions and Livelihood management seem to have higher frequencies compared to hard measures, indicating a preference for more environmentally friendly approaches. The districts which are more vulnerable due to Cyclones, it is recommended for the shelter belt plantations and ecosystem based storm surge barriers.



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Abbreviations

AR6	Sixth Assessment Report
CRI	Coastal Risk Index
CRZ	Coastal Regulation Zone
CVI	Coastal Vulnerability Index
CS	Cyclonic Storm
DEM	Digital Elevation Model
DSAS	Digital Shoreline Analysis System
EbA	Ecosystem-Based Adaptation
EPR	End Point Rate
ERDAS	Earth Resource Data Analysis System
ETM	Enhanced Thematic Mapper
FSI	Forest Survey of India
GCM	General Circulation Models
GHGs	Greenhouse gases
GIS	Geographic information systems
GMSL	Global Mean Sea Level
GPS	Global Positioning System
HTL	High Tide Line
IBTrACS	International Best Track Archive for Climate Stewardship
ICZM	Integrated Coastal Zone Management
JTWC	Joint Typhoon Warning Centre
IMD	India Meteorological Data
IPCC	Intergovernmental Panel on Climate Change
ISRO	Indian Space Research Organization
LISS	Linear Imaging Self-Scanning Sensor
LRR	Linear Regression Rate
LTL	Low Tide Line
LULC	Land Use Land Cover
MSL	Mean sea level
MSSRF	M.S. Swaminathan Research Foundation
NC	Near century
NCCR	National Centre for Coastal Research
NDVI	Normalized Difference Vegetation Index
NDWI	Normalized Difference Water Index
NIO	North Indian Ocean
NOAA	National Oceanic and Atmospheric Administration
NSM	Net Shoreline Movement
SCS	Severe Cyclonic Storm
SimCLIM	Simulator of Climate Change Risks and Adaptation Initiatives
SLR	Sea Level Rise
SSPs	Scenarios like the Shared Socio-economic Pathways
SST	Sea Surface Temperature
USGS	United States Geological Survey
TNSAPCC	Tamil Nadu State Action Plan on Climate Change
TN-SHORE	Tamil Nadu Sustainably Harnessing Ocean Resources and Blue Economy
TM	Thematic Mapper
UNFCCC	United Nations Framework Convention on Climate Change
UTM	Universal Transverse Mercator
VLM	Vertical Land Movement
WMO	World Metrological Organization

1. Introduction

Coastal environments are considered to be highly complex due to the intricate interplay of terrestrial, marine, and atmospheric processes that shape them (Dethier et al., 2011). These areas serve as the interface between the open sea and terrestrial watersheds, and they exhibit a wide range of spatial and temporal scales in both physical and biogeochemical processes (Werner et al., 2019). The coastal zone plays a crucial role in the global environment and are extremely valuable due to the various services they provide such as regulation, provisional and amenity services (Kais & Islam, 2023).

Sea level rise is one of the most significant impacts of climate change on coastal areas (Caron, 2009; Mimura, 2013). As global temperature increases, glaciers and ice caps melt, causing the sea level to rise (Cazenave and Remy, 2011; Cazenave and Cozannet, 2014; Hansen et al., 2015; Lindsey, 2021). This puts coastal communities at risk of increased flooding, erosion, and saltwater intrusion into freshwater sources (Klassen and Allen, 2017). Climate change can lead to more frequent and intense storms, and these storms can cause significant damage to coastal infrastructure and ecosystems (Michener et al., 1997). They can also result in coastal flooding and erosion, further exacerbating the vulnerability of these areas. Rising sea levels and increased storm activity contribute to coastal erosion. As waves and currents become stronger, they can erode beaches, cliffs, and dunes, leading to the loss of valuable land and habitats. This erosion can also threaten coastal infrastructure and communities and coastal ecosystems, such as mangroves, salt marshes, and coral reefs, which provide natural protection against storms. This loss reduces the natural defenses that coastal areas have against climate-related hazards. As coastal areas become more vulnerable to climate change impacts, communities may be forced to relocate due to increased flooding, erosion, and Sea Level Rise leading to loss of habitable land. This displacement can lead to social, economic, and cultural challenges for affected communities. Adaptation and mitigation strategies are crucial to address the vulnerability of coastal areas to climate change.

1.1 State at Glance

The 14 coastal districts of Tamil Nadu (Table 1) are bounded by the Bay of Bengal in the East, the Arabian sea in the West and the Indian Ocean in the South (Figure 1). The coastal length of Tamil

Nadu is categorized into the Coromandel coast from Pulicat to Point Calimere 357.2 km, Palk Bay from Point Calimere to Pamban 293.9 km, Gulf of Mannar from Pamban to Kanyakumari 364.9 km and west coast in the Arabian sea from Kanyakumari to Neerodi 60.0 km (Report: TN fisheries, 2022). The coasts are highly productive areas providing the nation's economic growth, and livelihood opportunities. The highly dynamic coastal environment is under threat due to climate change-induced extreme waves, cyclones, sea level rise, and coastal flooding.

Table 1. Coastal Length of Tamil Nadu

<table>
<tr><th>S. No</th><th>Districts</th><th>Coastal Length (km)</th><th>Coast Classification</th><th>Nature of the Coast</th></tr>
<tr><td>1</td><td>Tiruvallur</td><td>27.9</td><td rowspan="7">Coromandal coast</td><td rowspan="7">Alluvial plain coast</td></tr>
<tr><td>2</td><td>Chennai</td><td>19.0</td></tr>
<tr><td>3</td><td>Chengalpattu</td><td>87.2</td></tr>
<tr><td>4</td><td>Villupuram</td><td>40.7</td></tr>
<tr><td>5</td><td>Cuddalore</td><td>57.5</td></tr>
<tr><td>6</td><td>Mayiladuthurai</td><td>70.9</td></tr>
<tr><td>7</td><td>Nagapattinam</td><td>54.0</td></tr>
<tr><td>8</td><td>Tiruvarur</td><td>47.2</td><td rowspan="4">Palk Bay
(*) Both Palk Bay and Gulf of Mannar</td><td rowspan="4">Deltaic Coast</td></tr>
<tr><td>9</td><td>Thanjavur</td><td>45.1</td></tr>
<tr><td>10</td><td>Pudukkottai</td><td>42.8</td></tr>
<tr><td>11</td><td>Ramanathapuram (*)</td><td>236.8</td></tr>
<tr><td>12</td><td>Thuthookudi</td><td>163.5</td><td rowspan="2">Gulf of Mannar</td><td rowspan="2">Sand Dune Coast</td></tr>
<tr><td>13</td><td>Tirunelveli</td><td>48.9</td></tr>
<tr><td>14</td><td>Kanyakumari (*)</td><td>71.5</td><td>(*) Both Gulf of Mannar and West Coast</td><td>Barrier Beaches</td></tr>
</table>

Source: TN – Fisheries (2022), IIT Madras (2016)

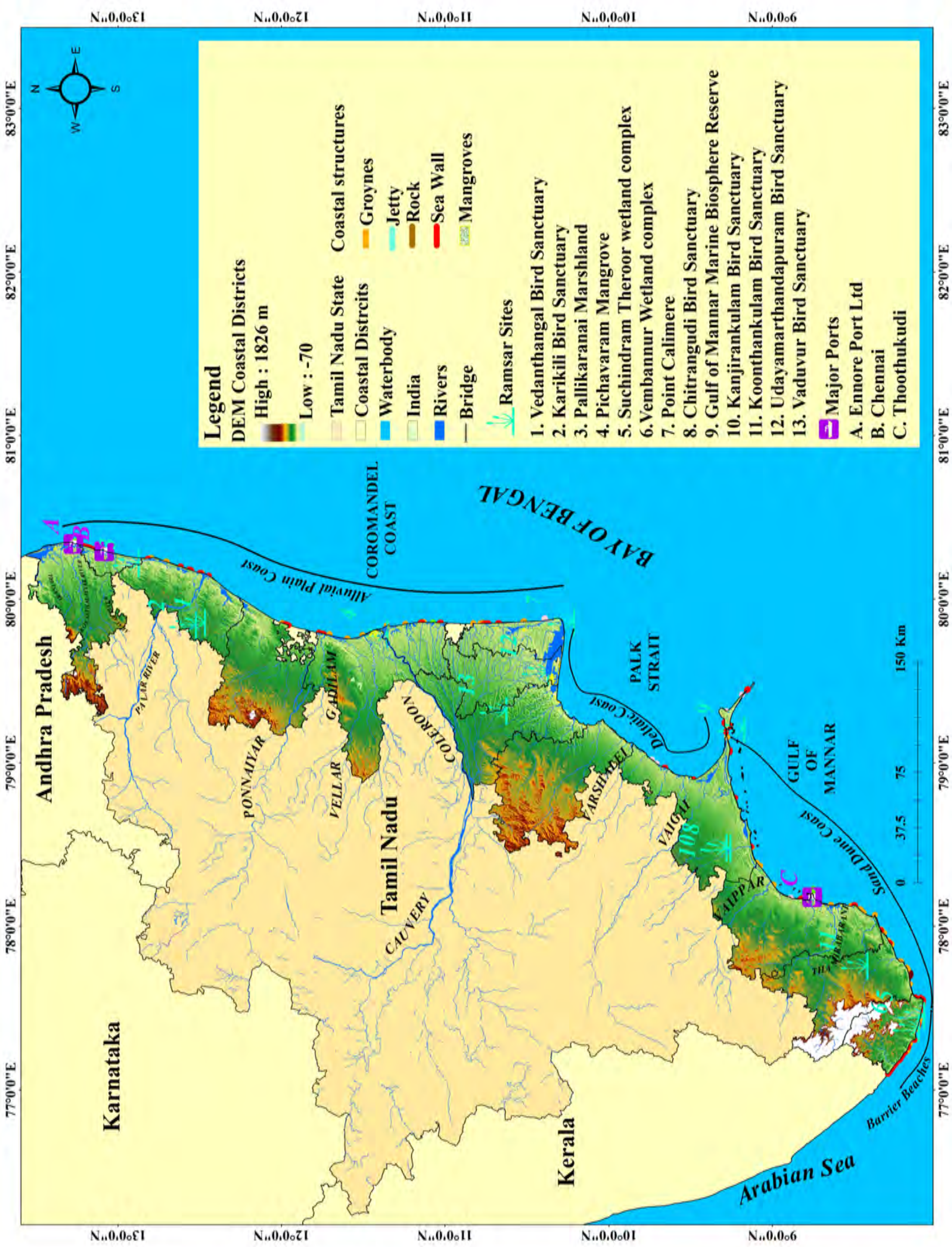


Figure 1 Coastal Profile Map of Tamil Nadu (2023) Coastal Resources Status

Tamil Nadu is rich in diverse and abundant coastal and marine resources. The shoreline of the state contains a variety of intertidal environments, such as brackishwater lagoons, estuaries, coastal marshes, mud flats, and sandy and rocky shorelines with varying levels of exposure and profile variations. Biodiversity-rich environments include coastal lagoons, mangroves, estuaries, wetlands, corals, and Seagrasses. Coastal and marine biodiversity is suffering nationwide due to a multitude of direct and indirect stresses resulting from various forms of climate extremities and economic development activities. In the following years, climate-induced effects on coastal ecosystems as a result of Sea Level Rise, shoreline change, tropical cyclones, and storm surges will escalate. The details of the resources are mentioned as follows,

1.2.1 Mangroves

Mangroves, which are predominantly found in tropical and sub-tropical intertidal regions, are salt-tolerant forest ecosystems. They serve a crucial and diverse array of functions in providing various ecosystem services Anu et al., 2024. Indian mangrove forests have an estimated cover of 4992 km^2 and are located along the nine coastal states and three union territories. Tamil Nadu is covered with 45 km^2 of mangrove forest. Among these, 1 km^2 of mangroves are highly dense, 27 km^2 are moderately dense, and 17 km^2 are open mangroves (Report: FSI, 2021). Along the coastline of Tamil Nadu, major mangrove wetlands are present at Pichavaram in the Cuddalore District and the other in the Muthupet region in the Thiruvarur-Thanjavur Districts. Small patches of mangroves are also present along Palk Bay, particularly in the Devipattinam region, and also in some of the islands of the Gulf of Mannar in Ramanathapuram District and Adayar Estuary in Chennai district.

1.2.1.1 Pichavaram mangroves

Pichavaram mangroves at Cuddalore district is located in the higher land of the Vellar-Coleroon estuarine complex and consists of three Reserve Forests (RF), namely Killai RF, Pichavaram RF, and Pichavaram Extension RF. According to a recent botanical survey conducted by the M.S.S.R.F, a total number of 12 true mangrove plant species are present in this mangrove wetland. The mangrove extends to an area of 1,100 hectares, representing a heterogeneous mixture of mangrove elements. The source of freshwater to this mangrove is from both the estuaries and seawater in the Bay of Bengal. The whole of the mangrove comprises about 51 small and large islands, with their sizes ranging from 10 m^2 to 2 km^2. The mangrove soil usually consists of alluvium derived from the mangrove plants. Pichavaram has a well-developed mangrove forest dominant with *Rhizophora spp., Avicennia marina*, *Exocaria agallocha, Bruguiera cylindrica, Lumnitzera racemosa, Ceriops decandra* and *Aegiceras corniculatum* as the dominant flora (Figure 2).

Figure 2 Rhizophora spp. along the fringes of Pichavaram.

1.2.1.2 Muthupet mangroves

Muthupet mangroves at Tiruvarur and Thanjavur districts lie close to Point Calimere on the Southeast coast of Peninsular India. It is at the southern end of the Cauvery delta, covering an area of approximately 6800 ha. of which only 4% is occupied by well-grown mangroves. Various tributaries of the river Cauveri flow through Muthupet and adjacent villages. At the tail end, they form a lagoon before meeting the Palk Strait. The northern and western borders of the lagoon are occupied by a sand spit that is devoid of mangrove vegetation. The Muthupet mangrove ecosystem embraces a heterogeneous mixture of mangrove elements of plants and animals. Among the six principal mangrove species, *Avicennia marina* is the most common and abundant, followed by *Exoecaria agallocha, Aegiceros corniculatum,* and *Acanthus ilicifolius* in that order.

1.2.1.3 Gulf of Mannar Mangroves

In the islands of the Gulf of Mannar, small patches of mangroves are present, and nine true mangrove species have been recorded. *Aegiceros corniculatum, Avicennia marina, Exocaria agallocha, Bruguiera cylindrica, Ceriops decandra, Lumnitzera racemosa, Rhizophora Apiculata,* *Rhizophora Mucronata*, and *Pemphis addula are abundant species. Pemphis Acidula* is endemic to these islands.

1.2.2 Coral Reefs

Coral reefs are underwater ecosystems formed by the accumulation and growth of coral polyps, which are tiny, soft-bodied organisms. It is found in shallow, warm, and clear waters, primarily in tropical and subtropical regions. Coral reefs are characterized by their vibrant and diverse marine life, including numerous species of fish, invertebrates, and plants. They play a crucial role in providing habitats for marine organisms, protecting coastlines from erosion, and supporting local economies through activities such as tourism and fishing.

The coral reefs in Tamil Nadu are distributed along the Gulf of Mannar, Palk Bay, and certain areas in Cuddalore. These reefs can be found scattered between 79° to 79°9'E to 8°45' to 9°11'N, covering approximately 21 islands from Tuticorin to Rameswaram. While most of the reefs are of the fringing variety around the islands, they form a discontinuous barrier known as the 'Mannar Barrier'. In the Gulf of Mannar, the foliaceous coral forms include Echinoptera, Lamellosa, and Montipora foliosa. In Palk Bay, the reef along the shore extends from Mandapam to Rameswaram island, with interruptions only at the Pamban pass. The corals in this area are mainly found on reef rocks, and there is no consolidated reef flat. The zonation of coral species is not distinct in this region. One significant impact on the distribution of corals on the reef is the siltation that occurs, particularly during the monsoon season, along the inshore region.

1.2.3 Sea Grass

Seagrasses are considered *'Ecosystem Engineers'* as they are known for providing many ecosystem services and are also called 'the lungs of the sea' as they release oxygen into the water through photosynthesis (Singh, et.al., 2019). These ecologically sensitive habitats are distributed densely between Anthiramapattinam and Pamban, covering three coastal districts, namely Tanjavur, Pudukkottai, and Ramanathapuram, with a coastal length of about 170 km (Edward et al., 2019).

The distribution of seagrass in the Gulf of Mannar has been extensively researched in recent years. There are 14 varieties of seagrass species found in India. In the Pamban area and along the southeast coast of Rameshwaram Island, Enhalus acoroides dominates. The lagoons of Krusadai, Pullivasal, and Pumarichan Islands sustain Cymodocea serrulata, Halodule uninervis, and Halophila ovalis. Other seagrass species found in the Gulf of Mannar include Cymodocea rotundata, Thalassia hemprichii, and Syringodium isoetifolium. The largest seagrass patch in the region covers an area of 39.22 km^2 and stretches across the shallow coastal areas of Mandapam and Keelakarai. This patch is primarily dominated by Cymodocea serrulata and Halodule uninervis (Geevarghese et al., 2018).

1.3 Blue Economy of Tamil Nadu

The coastal districts of Tamil Nadu provide several livelihood opportunities to the various communities. Goal No. 14 of the UN's Sustainable Development Goals pertains to "Life Below Water," with an emphasis on controlling Earth's climate, supplying millions of people with food and a means of subsistence, promoting biodiversity, and providing advantages for recreation and culture. The State is now in a key position to fully use the enormous potential of its maritime resources for sustained economic growth thanks to its advantageous geographic location. The term "blue economy" refers to a broad range of industries, including shipping, port infrastructure, marine tourism, fisheries, and offshore renewable energy. These industries all make major contributions to the socioeconomic development of the state. The Blue Economy of Tamil Nadu is mentioned in the Figure.3.

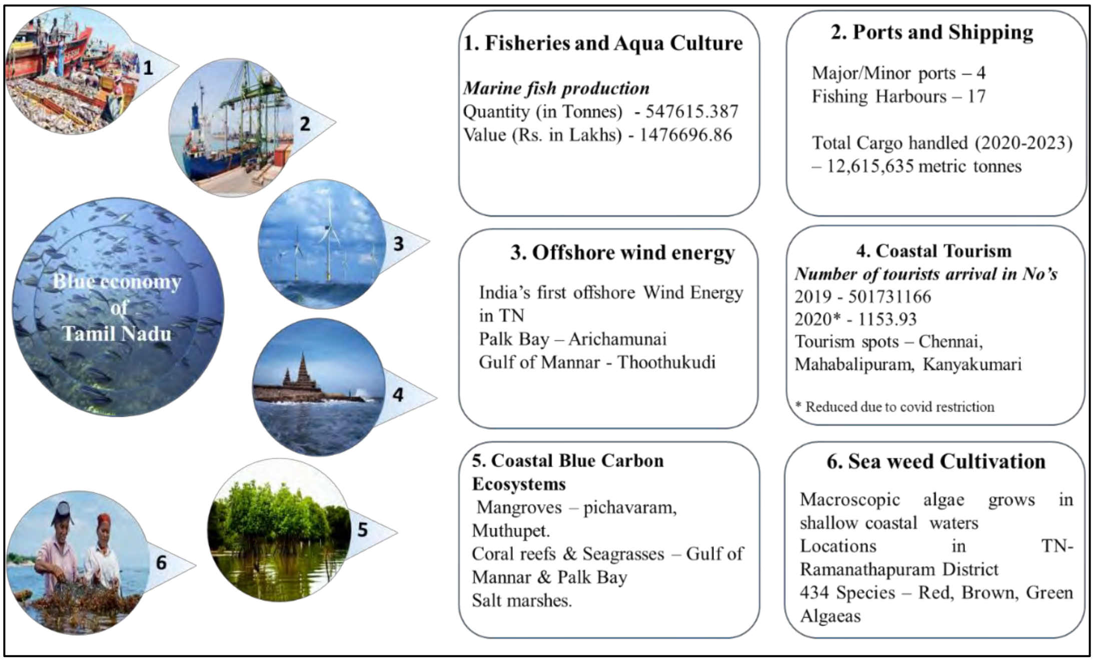


Figure 3 Status of Blue Economy of Tamil Nadu - 2022.

At present, there are 3 major ports and 15 minor ports (Table 2), 6 Fishing harbours and 11 Fish Landing Centres in Tamil Nadu. It provides livelihood opportunities to the coastal communities by promoting Blue Economy to the nation's growth.

Table 2. List of Ports of Tamil Nadu

S. No	District Name	Major ports	Minor Ports
1	Thiruvallur	Ennore port	Kattupalli
			Ennore Minor Port
2	Chennai	Chennai port	-
3	Cuddalore	-	Cuddalore
			Thiruchopuram
			PY-3 Oil Field
4	Nagapattinam	-	Nagapattinam
			Tirukkadaiyur
5	Ramanathapuram	-	Rameshwaram
			Pamban
			Valinokkam
6	Thoothukudi	Thoothukudi port	Punnakkayal
			Manappad
7	Tirunelveli	-	Kudankulam
8	Kanyakumari	-	Kanyakumari
			Colachel

Source: https://www.tn.gov.in/rti/proactive/highways/handbook-TNMB.pdf

1.3.1 Existing Coastal Protection Structures in Tamil Nadu

Coastal protection measures are generally hard, soft, or hybrid solutions depending on the coast. The Tamil Nadu coast occupies 13.5% of the coastal infrastructures, such as ports, harbors, and shore protection structures (NCCR, 2022). Though the hard structures protect the coast, they cause impacts on the adjoining coast. The interaction of the structures between waves and currents causes the longshore sediment pathway to result in downdrift erosion. Out of 13.5 % of coastal structures, 9.5 % are coastal protection structures, i.e., sea walls, Groins, and Jetty, and 4 % are coastal infrastructures, i.e., ports, fishing harbours, and fish landing centers (NCCR, 2022).

The existing structures along the coast of Tamil Nadu are digitized using Google Earth images of 2022. The resolution of images is 0.5 m, which will help in analyzing the coastal exposure to sea level rise (Figure 4).

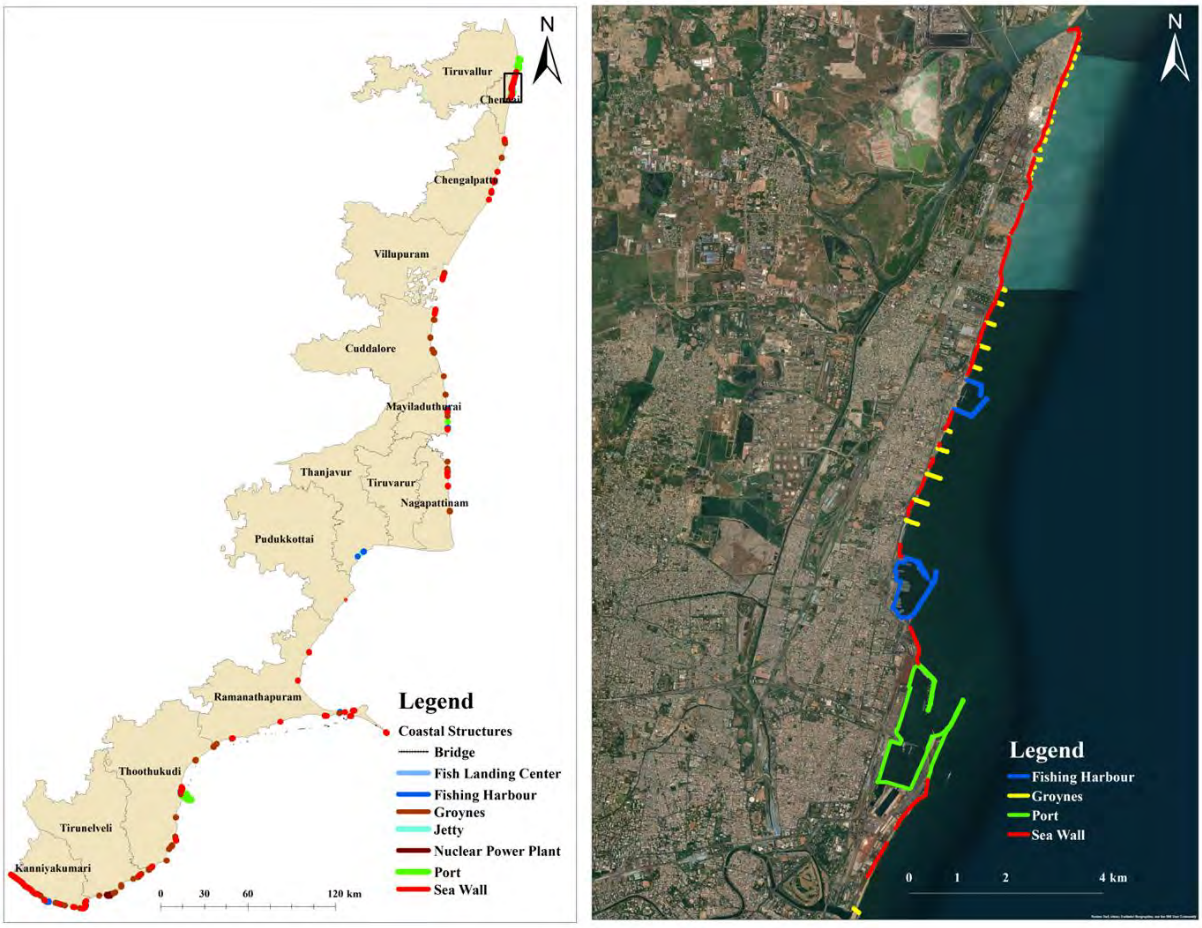


Figure 4 Existing coastal structures of Tamil Nadu – 2022

1.4 Opportunities and Challenges

The coastal zone plays an important role in mitigating and adapting to climate change. Coastal ecosystems like mangroves, Coral Reefs, salt marshes, and seagrass beds are highly effective at storing carbon dioxide (CO_2) from the atmosphere, helping to reduce greenhouse gas emissions and combat climate change (Alongi, 2014; Sanders et al., 2014; Brown et al., 2016). Coastal ecosystems act as natural barriers against storms, hurricanes, and flooding. They help to reduce the impact of these events by absorbing and dissipating the energy of waves and storm surges, by protecting coastal communities from extreme weather events, these ecosystems help to mitigate the effects of climate change (Prasetya, 2007). Climate Change dynamics, which operate on multiple spatial and temporal scales within the linked human-environmental system, create vulnerability by affecting individuals and communities ability to prepare, cope, and recover from the effects (Rubinato et al., 2020).

The rich coastal area of Tamil Nadu is flourished with the various blue carbon ecosystems, which provides an opportunity to mitigate the climate change impacts and promotes carbon credits at the global level. Despite this, Tamil Nadu coast is vulnerable to various climate change impacts such as sea-level rise, storm surge, and coastal erosion. Coastal Ecosystems are complex and dynamic, influenced by various natural and anthropogenic factors. Understanding and characterizing these dynamics can be challenging, especially in coastal areas with multiple interacting processes. Overall, despite the challenges, studying the coastal vulnerability of Tamil Nadu presents significant opportunities for understanding the impacts of climate change and developing strategies for sustainable coastal management and adaptation.

1.5 Overview of the Report

The Climate change risk assessment for the Coastal Districts of Tamil Nadu is paramount in addressing the risks and helps the stake holders to plan the better adaptation and mitigation strategies. The report focuses mainly on the following analysis to address the risk of the coastal area of Tamil Nadu.

1. Sea Level Rise projection using SimCLIM for AR6 SSP2-4.5 Scenario – Near Century (2005-2050) – Tamil Nadu
2. Sea Level Rise induced Coastal Inundation and its impact on Land Use Land Cover for IPCC AR6 SSP2-4.5 Scenario – Near Century (2005-2050)– Tamil Nadu
3. Shoreline Change Assessment of Tamil Nadu for the period of 1992-2022
4. Identification of Eroding Hotspots of Tamil Nadu for the period of 1992-2022
5. Land Loss and Land Gain Assessment of Tamil Nadu for the period of 1992-2022
6. Cyclone frequency and proximity to Severe Cyclonic Storm Track analysis of Tamil Nadu for the period of 1891-2022
7. Coastal Risk Assessment of Tamil Nadu for the Base Period (1992-2022) and Near Century (2023-2050)
8. Development of adaptation strategies to address climate-related risks in future scenarios

2. TAMIL NADU CLIMATE PROFILE

Climate Change is “a change in the State of the climate that can be identified by changes in the mean and/ or the variability of its properties and that persists for an extended period, typically decades or longer” (IPCC 2014). Anthropogenic climate change has been defined as “a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere (e.g. increase in greenhouse gases due to fossil fuel emissions) or surface characteristics (e.g. deforestation) and which is in addition to natural climate variability observed over comparable periods”.

Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes (IPCC 2021). It is reported that, in India, the mean annual temperature has increased by 0.6°C over the last century; the monsoon rainfall is declined over the last three decades of the 20th century in many parts of the country, while some parts have shown an increasing trend in the observed frequency of heavy precipitation events.

The climate of Tamil Nadu is strikingly different from the country’s general climate. Due to its topographical features and geographical area, the climate of Tamil Nadu is referred to as semi-arid and tropical monsoon. The long coastal stretch in the east, hills on the western rim, and a flat interior significantly influence the climate of the State, which is tropical with only little seasonal variation in summer and winter temperatures. Apart from a brief break during the monsoon season, the State experiences hot temperatures throughout the remaining months. Due to the proximity to the sea, the humidity remains relatively high. The summer is hot, with temperatures rising to 43℃ and extending from April to June. November to February is the coolest winter period, with temperatures around 18°C.

The State receives most of its annual rainfall during October, November, and December (post-monsoon). It is contrary to the rest of the country, where the rainy season comprises the months of June, July, August, and September. The State is frequently subjected to extreme weather conditions, such as flooding in the coastal districts and severe droughts in the interior due to monsoon failure. This has an adverse effect on agricultural production. Drought, water depletion, soil erosion, seawater incursion, forest fire, species extinction and thermal discomfort are major manifestations of climate change. Monsoon rains are the major water source for irrigation, making its linkages with the agricultural sector very critical.

Since the last decade, the State has been facing a noticeably higher incidence of cyclonic events (Vardah 2016, Ockhi 2017 and Gaja 2018) and severe floods (2015 and 2017). This warrants immediate action to analyse and understand the current and future climate trends of the State. This Chapter dwells upon Tamil Nadu's historical climatic trends based on India Meteorological Data (IMD) data for 1985 – 2014 and future projections about the climate and related uncertainties.

2.1 Temperature

The high resolution (0.25°x0.25° latitude and longitude) daily gridded rainfall datasets for 184 precipitation grids for a period of 30 years (1985– 2014) and 1.0°x1.0° latitude and longitude daily gridded temperature datasets for 23 temperature grids, spanning over 30 years (1985-2014) for maximum and minimum temperatures provided by IMD (https://www.imdpune.gov.in/lrfindex.php) have been used to calculate the spatial variability in precipitation and temperature respectively.

2.1.1 Maximum Temperature

It can be seen that the mean annual maximum temperature for Tamil Nadu is 32.5°C, with a range varying from 29.5°C to 33.4°C. It is also observed that for annual maximum temperature, the highest value is attained for the districts, viz., Chennai, Kancheepuram, Chengalpattu, Thiruvallur, Tiruvarur and Cuddalore, while the lowest value is attained for the Nilgiris district of Tamil Nadu.

2.1.2 Minimum Temperature

Mean annual minimum temperature is 22.6°C, varying from 19.4°C to 24.1°C. It is also seen that for annual minimum temperature, the highest value is attained for the district Tiruvarur, followed by Cuddalore, Mayiladuthurai and Nagapattinam, districts while the lowest value is attained for the district, Nilgiris: lying in Hilly Zone, for the period 1985-2014 (30 years). The annual average maximum and minimum temperature spatial variation of Tamil Nadu for the baseline period is given in Figure 5.

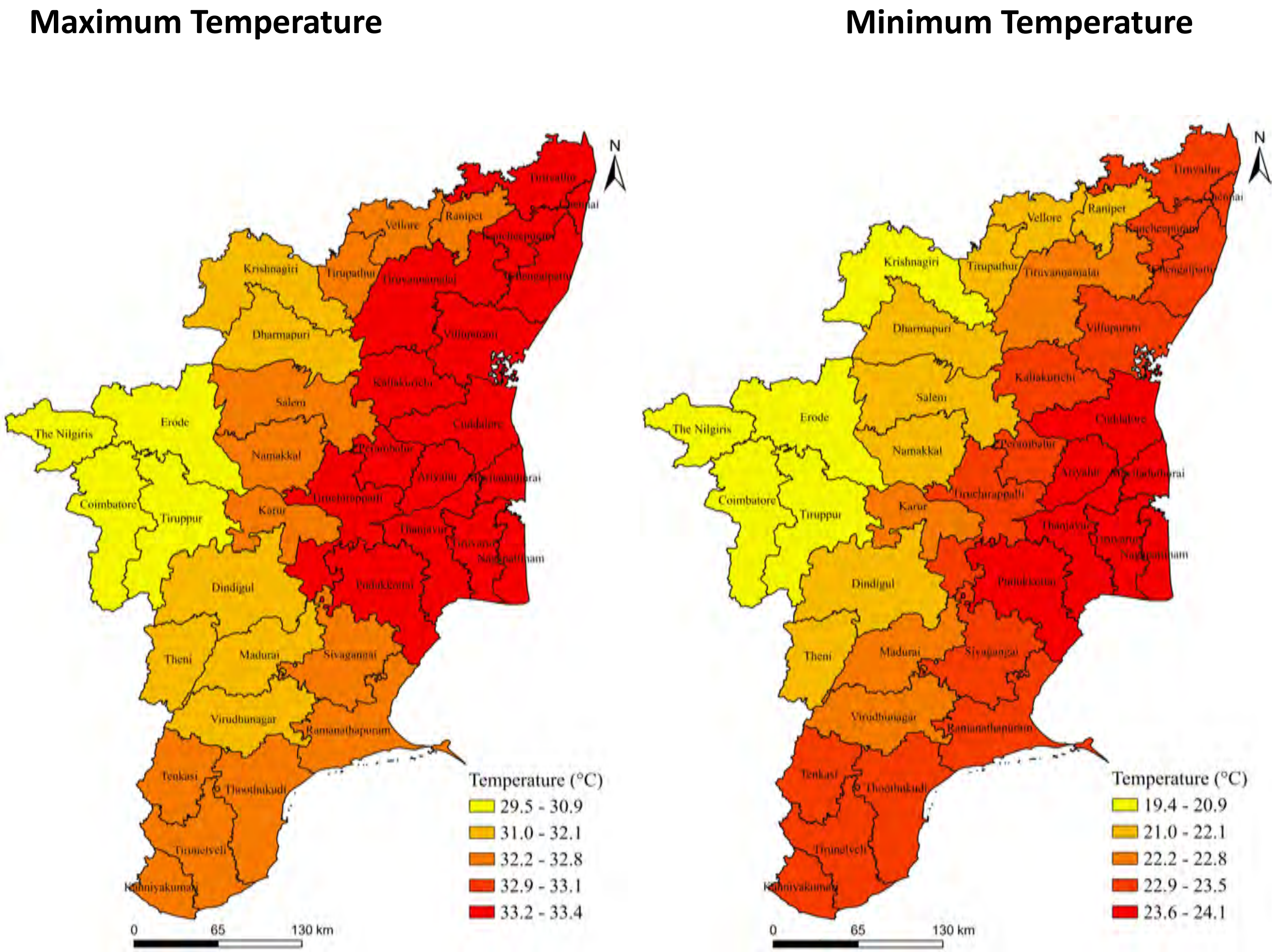


Figure 5 Observed Annual Maximum and Minimum Temperature of Tamil Nadu (1985-2014)

2.2 Rainfall

The average annual rainfall of Tamil Nadu is 987 mm within the district values ranging from 708 mm to 1406 mm over 30 years (1985-2014). As depicted in Figure 6, among all districts, The Nilgiris, Thiruvallur, Chennai, Kancheepuram, Chengalpattu, Cuddalore, Tiruvarur, Mayiladuthurai and Nagapattinam receive the maximum average annual rainfall. In contrast, Erode, Tiruppur, Karur, Tenkasi, Thoothukudi and Tirunelveli receives the lowest annual average rainfall.

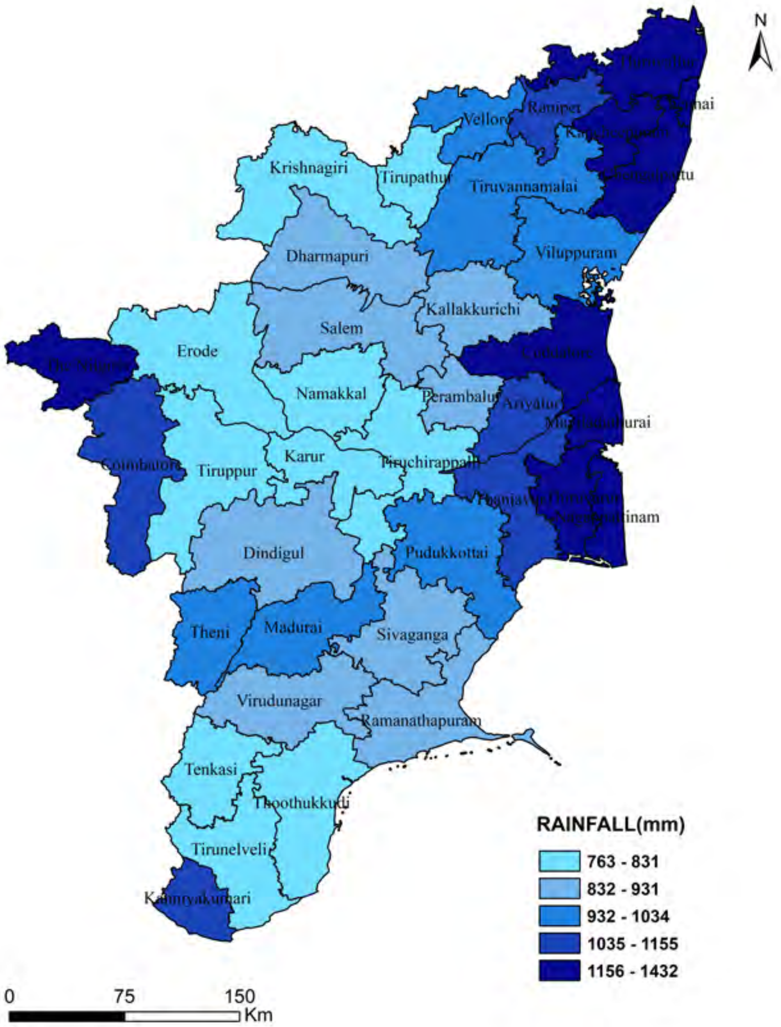


Figure 6 Spatial Variation in Observed Annual Rainfall of Tamil Nadu (1985-2014)

2.3 Climate Change Scenario

Climate change is the long-term alteration in Earth's climate patterns, primarily caused by human activities. It is driven by releasing greenhouse gases (GHGs) into the atmosphere by burning fossil fuels. This process, known as global warming, leads to changes in temperature, precipitation, wind patterns, and other factors that affect the planet's climate system. The consequences of climate change are wide-ranging, impacting ecosystems, agriculture, water resources, and human health. Addressing climate change requires global cooperation, mitigation of GHG emissions, and adaptation measures to minimise its adverse effects. The temperature anomaly of Tamil Nadu is shown in Figure 7.

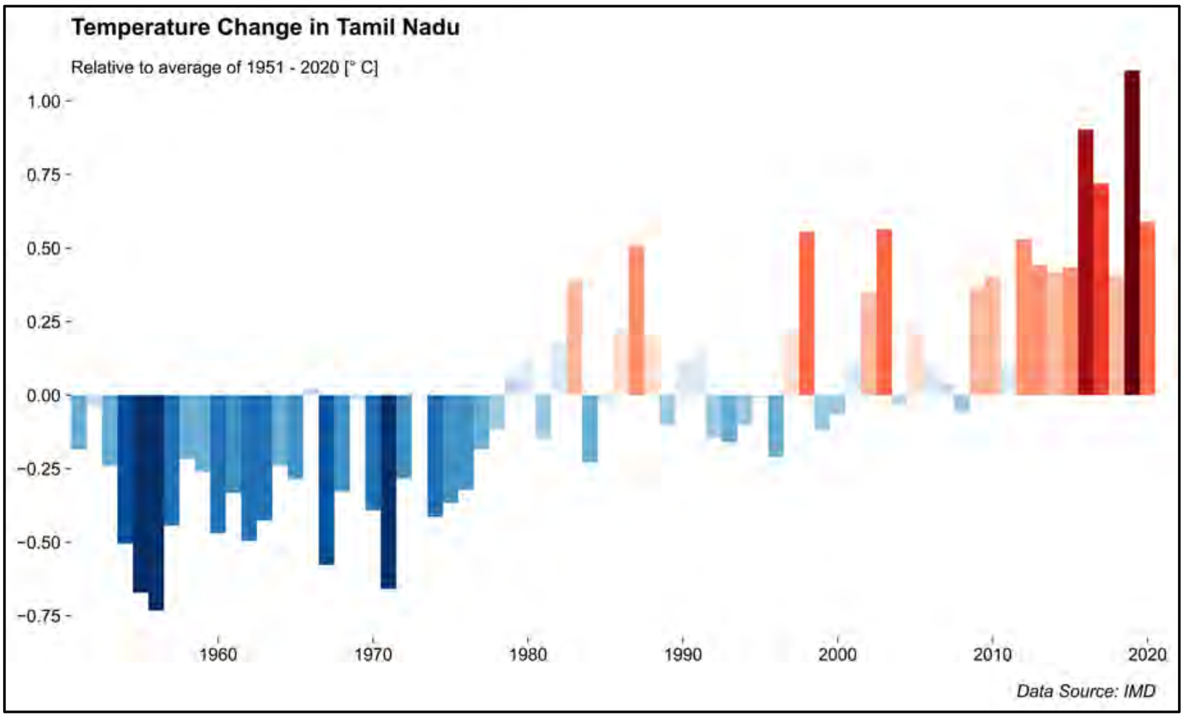


Figure 7 Temperature Change in Tamil Nadu since 1951

3.1 Causes and Impacts of Climate Change

Climate change is primarily caused by human activities, including burning fossil fuels and deforestation, which release GHGs and alter the planet's carbon balance. The increased concentration of GHGs leads to the enhanced greenhouse effect, resulting in rising temperatures, changing precipitation patterns, extreme weather events, sea-level rise, loss of biodiversity, and negative impacts on human health, agriculture, and water resources. These interconnected impacts highlight the urgent need to reduce GHG emissions and implement adaptation strategies.

3.2 Climate Change Projections and Scenarios

Climate change projections and scenarios provide insights into future climate conditions (Figure. 5). Climate models simulate the Earth's climate, considering factors such as GHG emissions, atmospheric composition, solar radiation, and land surface characteristics. These models generate projections of future climate conditions.

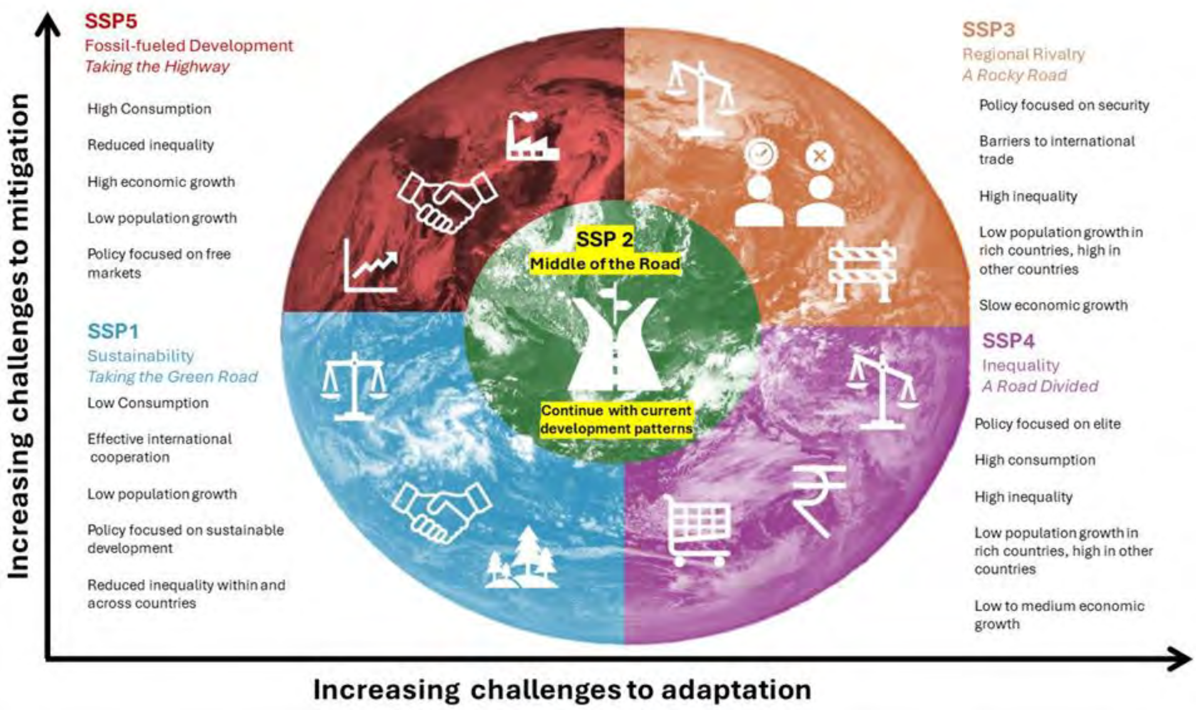


Figure 8 SSPs mapped in the challenges to mitigation/adaptation space

Scenarios like the Shared Socio-economic Pathways (SSPs) explore different future trajectories based on socio-economic factors. The SSPs categorise scenarios into SSP 1 - sustainability, SSP 2 - middle-of-the-road, SSP 3 - regional rivalry, SSP 4 - inequality, and SSP 5 - fossil-fueled development, representing different socio-economic and emission pathways. Figure 8 shows an SSP matrix that defines five possible SSPs in terms of different degrees of "challenges to adaptation" (or ability to deal with climate change that has already occurred) and "challenges to mitigation" (or ability to restrain the extent to which climate change will occur) as well as other features of socio-economic development.

3.3 Importance of Climate Change Projections and Scenarios

Climate change projections and scenarios help policymakers, scientists, and the general public understand potential impacts and plan for adaptation and mitigation. They assist in assessing risks and developing strategies based on socio-economic choices. The recently released Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) incorporates the SSPs to explore different socio-economic development pathways and their associated climate change consequences. These scenarios enhance our understanding of the complex interactions between human activities and climate change, guiding decision-making processes for climate mitigation and adaptation.

Climate change is a global challenge requiring collective action to mitigate its effects and build resilience. Human activities, primarily burning fossil fuels, are the main drivers of climate change. The impacts of climate change are wide-ranging, affecting ecosystems, agriculture, water resources, and human well-being. Climate change projections and scenarios provide valuable insights into future climate conditions and assist in developing adaptation and mitigation strategies. The IPCC AR6 and the SSPs offer a range of scenarios representing different socio-economic and emission pathways, highlighting the importance of sustainable development and urgent actions to transition to a low-carbon economy. By understanding the causes, impacts, and potential future climate change conditions, we can make informed decisions to protect our planet and future generations.

The EC-Earth3 model is statistically downscaled using PyClim-SDM (Statistical Downscaling model) from 100×100 km spatial resolution to 25×25 km spatial resolution for Tamil Nadu for the Shared Socio-economic Pathway scenario SSP2 4.5(Mid Pathways) and SSP5 8.5(Business as Usual) of IPCC AR6 and are projected for temperature and precipitation from 2021-2100. Figure 9 and Figure 10 indicate the projected changes in annual maximum temperature by near, mid and end term under SSP2 4.5 and SSP5 8.5, respectively.

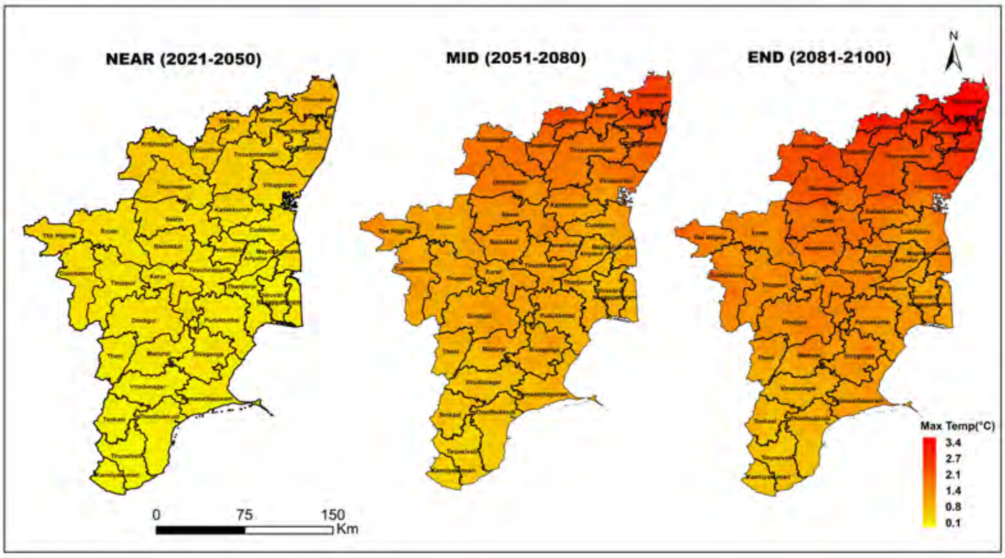


Figure 9 Projected Changes in Annual Maximum Temperature under SSP2 4.5

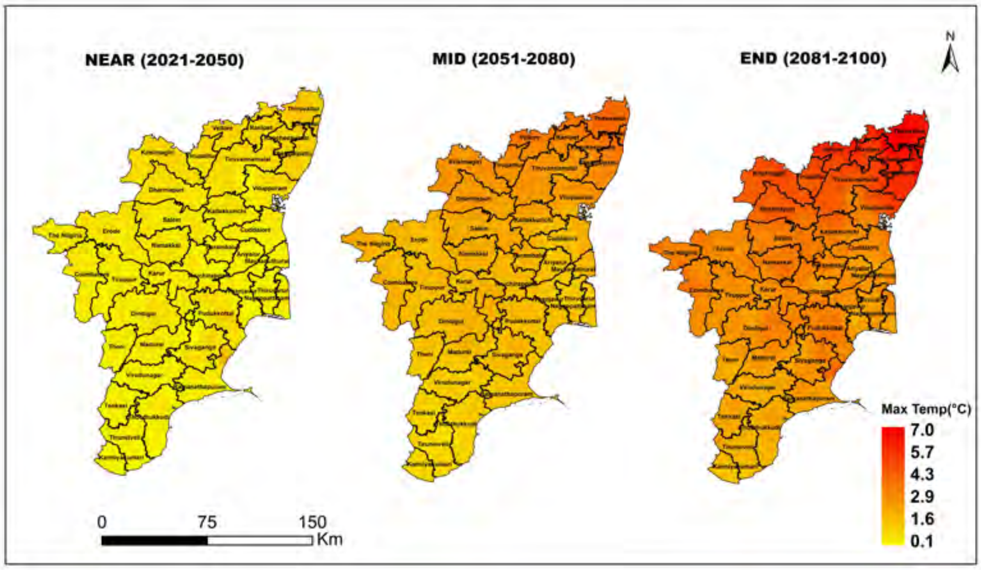


Figure 10 Projected Changes in Annual Maximum Temperature under SSP5 8.5

> *The northern Coastal districts such as Chennai, Nagapattinam, Kanyakumari, and Mayiladuthurai are projected to have a maximum increase in temperature by the end of the century.*

Table 3 indicates that the annual mean maximum temperature in the State may rise by up to 0.4 °C, 1.3°C and 1.7 °C in near-century, mid-century and end-century, respectively, under the SSP2-4.5 scenario and for the SSP5-8.5 scenario, the maximum temperature may rise by 0.6°C, 1.7°C and 3.5°C by near-century, mid-century and end-century respectively.

Table 3. Change in Annual Average Maximum Temperature

Projection Period	Increase in Annual Maximum Temperature with reference to baseline (°C)	
	SSP2-4.5 Scenario	SSP5-8.5 Scenario
Near Century (2021-2050)	0.4	0.6
Mid Century (2051-2080)	1.3	1.7
End Century (2081-2100)	1.7	3.5

It is observed that the annual mean maximum temperature in the State may rise by up to 0.4 °C, 1.3°C and 1.7 °C in near-century, mid-century and by end-century, respectively, under SSP2 4.5 scenario and with respect to the SSP5 8.5 scenario, the maximum temperature may rise by 0.6°C, 2.0°C and 3.6°C by near-century, mid-century and end-century respectively. The northern districts such as Chennai, Nagapattinam, Kanyakumari, and Mayiladuthurai are projected to have a maximum increase in temperature by the end of the century. The Average rainfall in Tamil Nadu State may increase marginally, by 4% towards the near century, 11% by the mid-century, and about 16% towards the end-century under the SSP2 4.5 scenario (Figure 11). Under the SSP5 8.5 scenario, the increase in rainfall is by 7% towards the near century, 18% in the mid-century, and 26% towards the end century (Figure 12).

Table 4. Percentage Change in Annual Average Rainfall

Projection Period	Increase in Annual Rainfall with reference to baseline (%)	
	SSP2-4.5 Scenario	SSP5-8.5 Scenario
Near Century (2021-2050)	4	7
Mid Century (2051-2080)	11	18
End Century (2081-2100)	16	26

Table 4 indicates that the Average rainfall in Tamil Nadu State may increase marginally, by 4% towards the near century, 11% by the mid-century, and about 16% towards the end-century under the SSP2-4.5 scenario (Fig 11). Under the SSP5-8.5 scenario, the increase in rainfall is by 7% towards the near century, 18% in the mid-century, and 26% towards the end of the century (Fig 12).

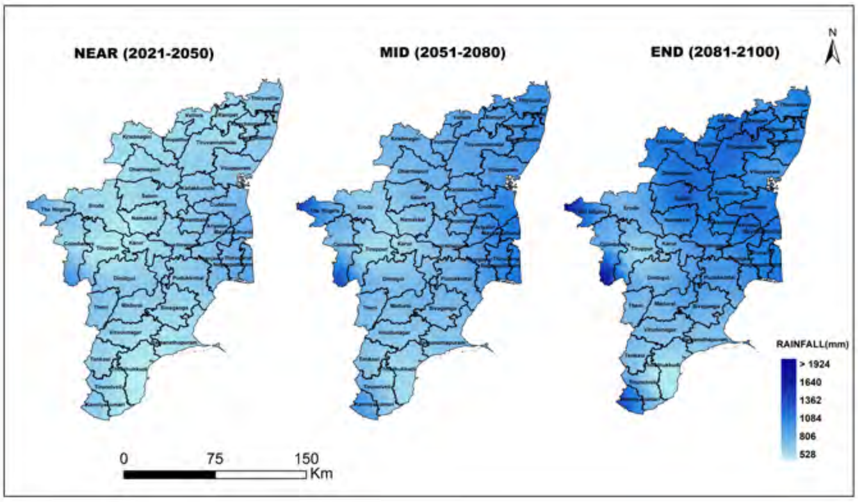


Figure 11 Projected Average Annual Rainfall under SSP2 4.5

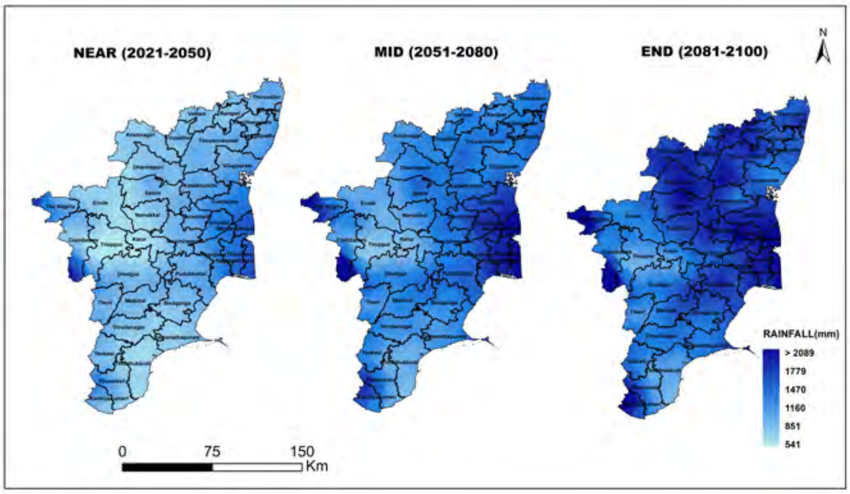


Figure 12 Projected Average Annual Rainfall under SSP5-8.5

> *It is inferred that coastal districts such as Cuddalore, Nagapattinam, Kanyakumari, and Mayiladuthurai are projected to have a maximum increase in rainfall by the end of the century.*

3. COASTAL IMPACTS, VULNERABILITY, AND RISKS

Ocean and coastal ecosystems play a crucial role in Earth's life and human well-being, covering two-thirds of the planet and hosting vast biodiversity. Coastal systems extend from the high-water mark to the edge of the continental shelf and include soft sediments, rocky shores, reefs, embayment's, estuaries, deltas, and shelf systems. As per CRZ notification 2019, the coastal zone is the land area from High Tide Line to 500 meters on the landward side along the sea front and water and the bed area between the LTL to the territorial water limit (12 Nautical miles). Sea level rise risks for coastal ecosystems and people are likely to increase tenfold before 2100 without adaptation and mitigation action. Under emission scenarios that do not limit warming to 1.5°C, coastal erosion, submergence of coastal land, loss of habitat and ecosystems, and worsening groundwater salinization will increase, compromising ecosystems and livelihoods. Extreme sea level events are projected to occur at least annually at more than half of all tide gauge locations by 2100, increasing risks for coastal ecosystems, people, and infrastructure beyond 2100 (IPCC, 2022).

The Tamil Nadu coast, home to diverse ecosystems like mangroves, estuaries, lagoons, and coral reefs, presents an opportunity to study their vulnerability to climate change stressors such as coastal erosion, sea level rise, tropical cyclones, and storm surges. The high population density of urban areas and fishing communities in the coastal region also provides an opportunity for the Blue economy. Owing to its great importance, it is paramount to understand the vulnerability of coastal areas to climate change effects and develop appropriate adaptation plans.

3.1 Climate Risk Assessment

The term "climate risk" refers to a conceptual framework Figure:13 that helps explain how ecosystems, biodiversity, and human systems are being affected by the more severe, interlinked, and frequently irreversible effects of climate change. The dynamic interconnections between climate-related hazards, exposure, and Vulnerability can give rise to risk in the context of climate change. The interplay of many threats increases total risk by creating additional avenues for sensitivity to climatic disasters. In this study, the climate risk was evaluated for the base period (1992– 2022) and Near century (2023 – 2050. Considering the essential indicators for the risk assessment will pave the way for understanding the coastal risk of the Tamil Nadu Coastline.

Hazard

Hazard is defined as the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. *(IPCC, 2022)*.

Vulnerability

Vulnerability is defined as the propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt *(IPCC, 2022)*.

Exposure

Exposure is defined as the presence of people; livelihoods; species or ecosystems; environmental functions, services, and resources; infrastructure; or economic, social or cultural assets in places and settings that could be adversely affected *(IPCC, 2022)*.

Risk

Risk is defined as the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system *(IPCC, 2022)*.

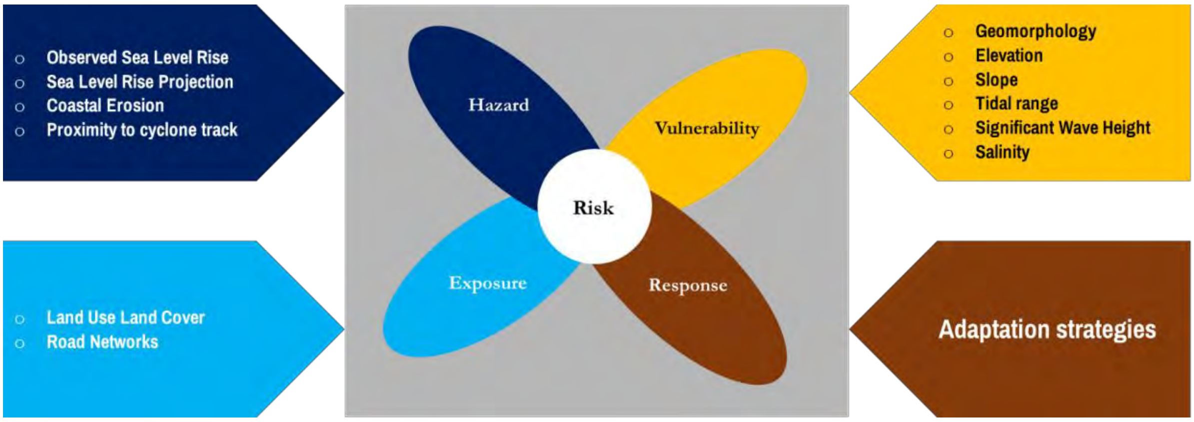


Figure 13 Conceptualization of Risk Frame work – IPCC AR6

3.2 Coastal Risk Assessment Methodology

The coastal risk assessment in this study is based on considering the essential indicators as mentioned in IPCC frame work Figure 14. The Coastal Vulnearbility Index (CVI) for climate change, primarily SLR for the US coast developed by Gornitz and Kanciruk was utilized in this study to assess the coastal risk index, Hossain et.al., 2022, Gornitz et.al.,1989, Gornitz et.al., 1991, Thieler et.al.,1999.

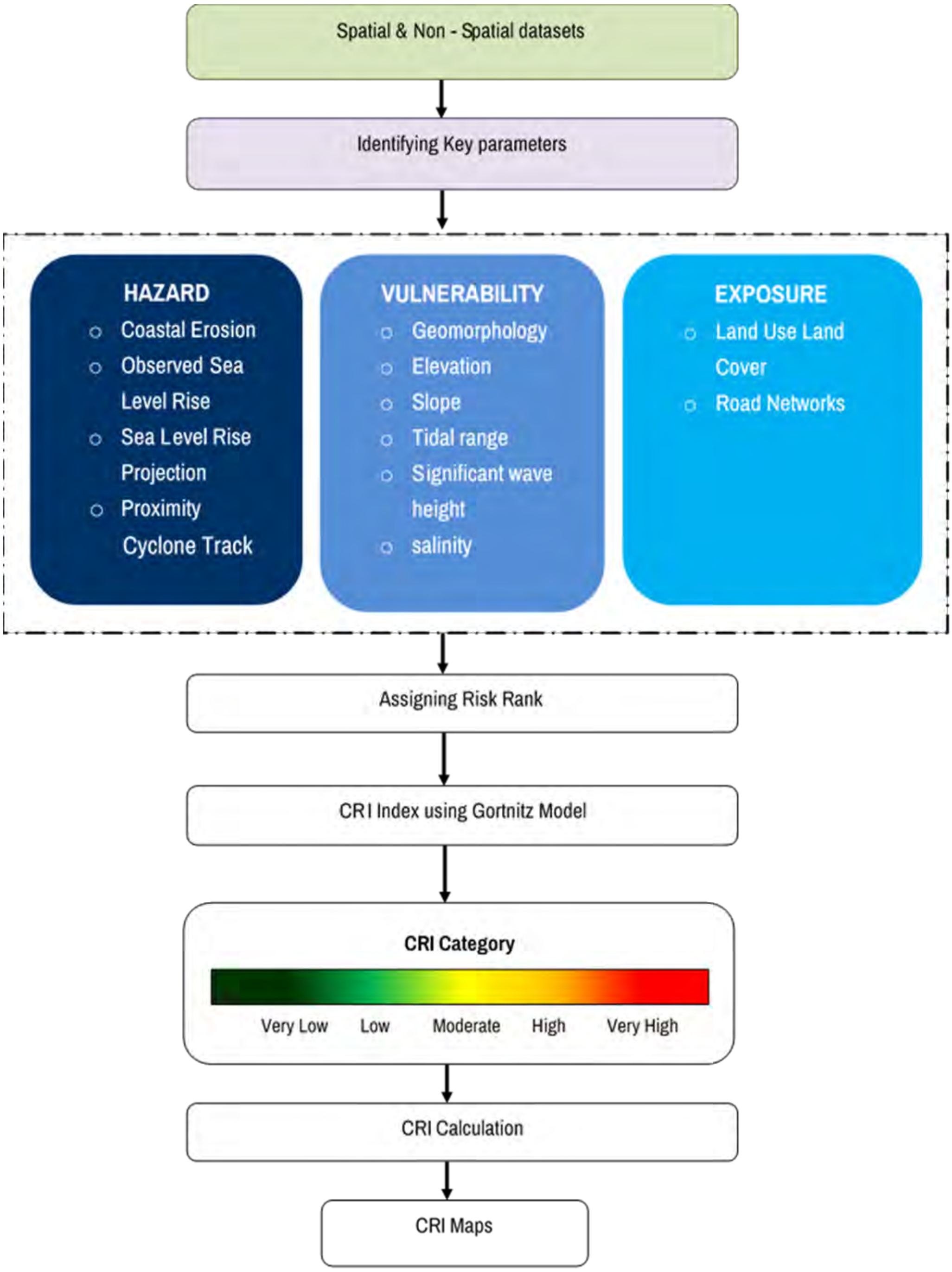


Figure 14 Coastal Risk Assessment Methodology

3.3 Coastal Hazard Assessment of Tamil Nadu

Hazard is defined as the potential occurrence of a natural or human-induced physical event or trend that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources. (IPCC, 2022). In context with, coastal hazards such as shoreline changes, Sea level rise, and tropical cyclones has the potential to cause damage to, or loss of, coastal ecosystems, buildings, infrastructures and coastal communities. The detailed Coastal hazard assessment as follows,

I. Sea Level Rise projection using SimCLIM for AR6 SSP2-4.5 Scenario – Near Century (2005-2050) – Tamil Nadu
II. Land Use Land Cover Assessment of Tamil Nadu - 2022
III. Sea Level Rise induced Coastal Inundation and its impact on Land Use Land Cover for IPCC AR6 SSP2-4.5 Scenario – Near Century (2005-2050)– Tamil Nadu
IV. Shoreline Change Assessment of Tamil Nadu for the period of 1992-2022
V. Identification of Eroding Hotspots of Tamil Nadu for the period of 1992-2022
VI. Land Loss and Land Gain Assessment of Tamil Nadu for the period of 1992-2022
VII. Cyclone frequency and proximity to Severe Cyclonic Storm Track analysis of Tamil Nadu for the period of 1891-2022

3.4 Sea Level Rise projection of Tamil Nadu

3.4.1 Sea Level Rise

Global mean sea level (GMSL) has risen by about 0.20 m since 1901 and continues to accelerate IPCC, 2021. Regional Sea Level (RSL) is the change in the mean sea level relative to the land. Regional rates of RSL rise differ from the global mean due to a range of factors, including local subsidence driven by anthropogenic activities such as groundwater and hydrocarbon extraction. Rising mean RSL will continue to drive an increase in the frequency of extreme sea levels. The expected frequency of the current 1-in-100-year extreme sea level is projected to increase by a median of 20–30 times across tide-gauge sites by 2050, regardless of emission scenario.

Sea level rise is unavoidable for centuries to millennia due to continuing deep Ocean warming, and ice sheet melt, and sea levels will remain elevated for thousands of years (high confidence). Global mean sea level rise will continue in the 21st century (virtually certain), with projected regional relative sea level rise within 20% of the global mean along two-thirds of the global coastline (medium confidence). Over the next 2000 years, global mean sea level will rise by about 2 - 3 m if warming is limited to

1.5°C and 2 - 6 m if limited to 2°C (low confidence). The global mean sea level rise projection of global rise relative to 1986-2005 is based on ocean thermal expansion calculated from climate models, the contributions from glaciers, Greenland and Antarctica from surface mass balance calculations using climate model temperature projections (IPCC AR5).

According to the Intergovernmental Panel for Climate Change (IPCC), sea-level rise resulting from climate change is an unavoidable phenomenon that will continue beyond the year 2100 (IPCC, 2018). The constant increase in global warming exacerbates the vulnerability of small islands, low-lying coastal areas, and deltas to various risks associated with rising sea levels. These risks include heightened saltwater intrusion, more frequent flooding, and infrastructure damage, posing significant threats to both human and ecological systems. To accurately evaluate the potential impact of future sea level rise and its consequences, it is necessary to analyze both climate change pathways and various scenarios of socioeconomic development.

Contributors to Sea Level Rise

a. Global Mean Sea Level

Global mean sea level offers an integrated assessment of the condition of the climate system, comprising both the ocean and cryosphere (parts of Earth covered in ice). Global mean sea level (GMSL) fluctuations over an extended period are primarily caused by three processes:

Global Mean Sea Level = Ice Melt + Thermal Expansion + Land water storage

b. Regional Relative Sea-Level Change

Global sea-level rise serves as a significant indicator of climate change. An increase in global atmospheric temperatures directly impacts the ocean, resulting in higher Sea Surface temperatures and glacier melting, ultimately contributing to the rise in global sea levels (Unnikrishnan et.al., 2007). A multitude of physical factors that differ in both time and location affect regional relative sea-level change, which can cause significant regional variations from the long-term rate of global mean sea-level rise. We describe regional relative sea-level change as follows, where each process varies both spatially and temporally:

Regional Relative Sea Level = Short-Term Effects + Sterodynamic Variability + Glaciers + Land Water Storage + Ice Sheets + Subsidence

3.4.2 Observed Sea Level Rise along Tamil Nadu

The Tamil Nadu coast has three tide gauge stations (Chennai, Nagapattinam, and Tuticorin) from which observed sea level data is obtained. However, the availability of data varies across the stations, as each station has limited information for different time periods (Table 5). The Permanent Service for Mean Sea Level (PSMSL) provides access to the downloaded observed mean sea level (MSL) data and the relative sea level trend for analysis.

Table 5. Tide Gauge Stations details

Details/ Tide Gauge	Chennai	Nagapattinam	Tuticorin
Station ID	205	1308	1072
Latitude	13°06'00.0"N	10°45'52.2"N	8°45'18.0"N
Longitude	80°18'00.0"E	79°50'59.1"E	78°11'43.3"E
Time span of data	1916 – 2015	1971 – 2021	1964 – 2021

The figure 15 shows that relative sea level trend is 0.55 millimetres/year with a 95% confidence interval of +/- 0.34 mm/yr based on monthly mean sea level data from 1916 to 2015 which is equivalent to a change of 0.18 feet in 100 years.

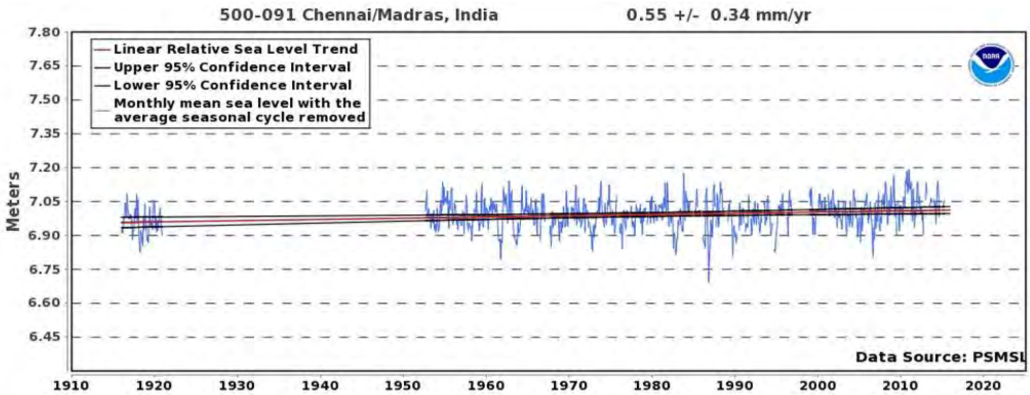
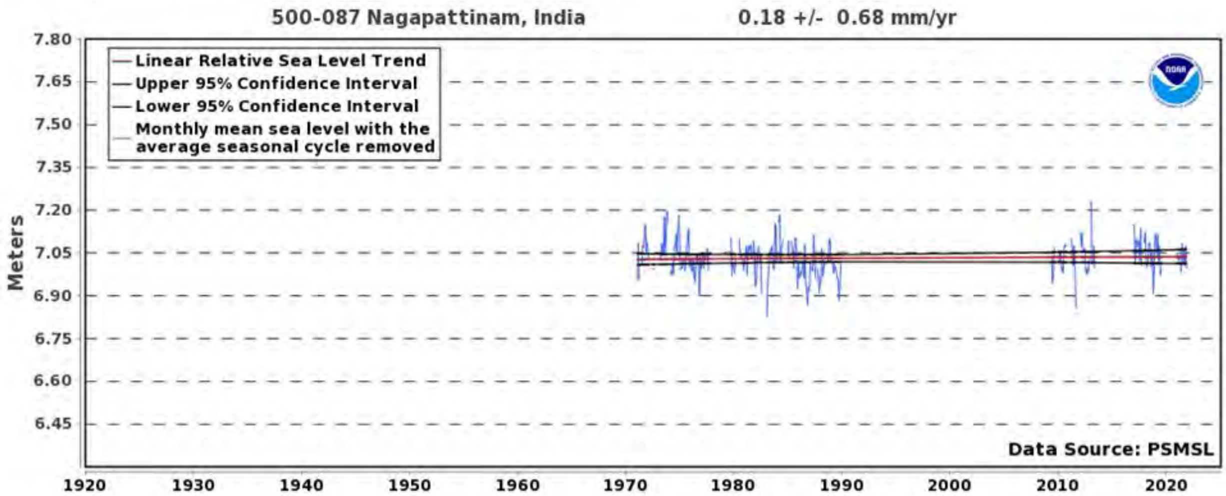


Figure 15 Observed Sea Level at Chennai Tide Gauge Station

The figure 16 shows that relative sea level trend is 0.18 millimeters/year with a 95% confidence interval of +/- 0.68 mm/yr based on monthly mean sea level data from 1971 to 2021 which



is equivalent to a change of 0.06 feet in 100 years.

Figure 16 Observed Sea Level at Nagapattinam Tide Gauge Station

The figure 17 shows that relative sea level trend is -0.17 millimeters/year with a 95% confidence interval of +/- 0.72 mm/yr based on monthly mean sea level data from 1964 to 2021 which is equivalent to a change of -0.06 feet in 100 years.

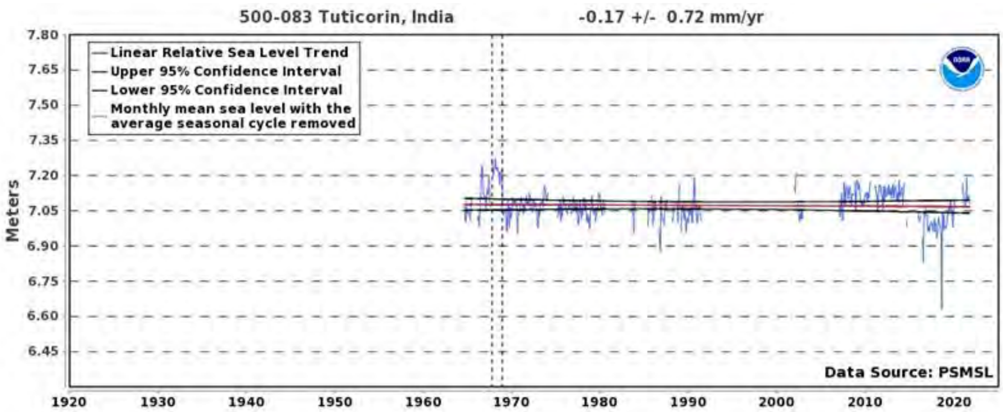


Figure 17 Observed Sea Level at Tuticorin Tide Gauge Station

3.4.3 Sea level rise projections of Tamil Nadu

In present study, the Sea Level Rise (SLR) projections for the Shared Socioeconomic Pathway (SSP) - 2 4.5 scenarios were utilized to estimate the potential sea level rise in the near-century for the coast of Tamil Nadu. The simulation tool SimCLIM (AR6) was employed for this purpose. The SimCLIM tool projected the Regional Sea Level Rise of the Tamil Nadu Coast. The Sea Level Rise

Projection period begins form 2005 to 2050 using the ensemble of 39 Global Climatic Models. The sea level is computed using the formula below,

$$\Delta RSL = \Delta SLG + \Delta SLRM + \Delta SLRG + \Delta SLVLM$$

ΔRSL = Relative sea-level change, ΔSLG = Global mean sea-level change, ΔSLRM = Regional variation in sea level from the global mean due to metro-oceanographic factors, ΔSLRG = Regional variation in sea level due to changes in the earth's gravitational field, and ΔSLVLM = Change in sea level due to vertical land movement.

Sea Level Rise Projection for SSP2 - 4.5 (AR6) – 2050

The Sea Level Rise is projected using the ensemble of Global Climatic models, for the low, mid and high projections. The short-term projection of the total trend of SLR for the Tamil Nadu coast based on the SSP2 - 4.5 scenario (Medium Projection) for the near century (2050) is estimated at an average of 19.7 cm (Figure 18). The Cuddalore district ranks high in the SLR projection of 20.26 cm in 2050, followed by Kanyakumari and Tirunelveli districts with an SLR projection of 20.16 cm, as compared with other coastal districts of Tamil Nadu, while Tirunelveli and Chennai districts rank least in the SLR projection of 19.19 cm in 2050) (Table 6).

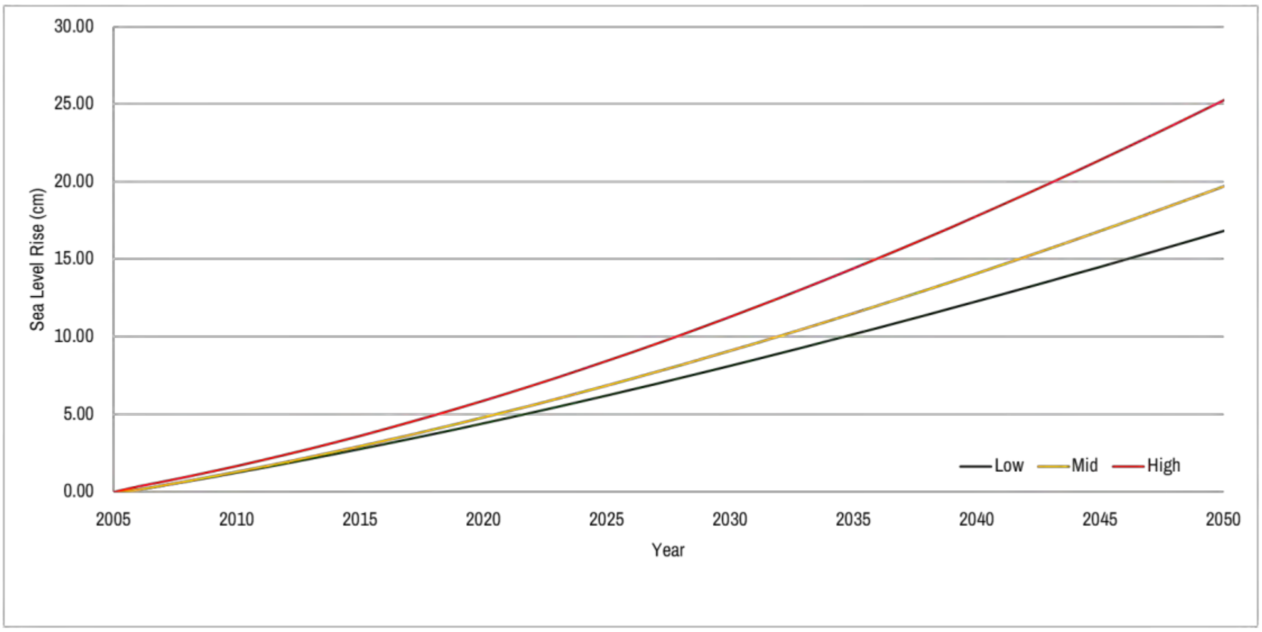


Figure 18 Sea Level Rise Projection of Tamil Nadu – SSP2- 4.5 – 2050

Table 6. Sea Level Rise Projection of Coastal Districts of Tamil Nadu

S. No.	District	SLR (cm) SSP 2-4.5 – Near Century		
		Low	Mid	High
1	Tiruvallur	16.4	19.2	24.6
2	Chennai	16.4	19.2	24.6
3	Chengalpattu	16.4	19.3	24.7
4	Villupuram	16.5	19.3	24.7
5	Cuddalore	17.3	20.3	26.0
6	Mayiladuthurai	16.5	19.3	24.7
7	Nagapattinam	16.6	19.4	24.9
8	Tiruvarur	16.8	19.7	25.3
9	Thanjavur	17.0	19.9	25.5
10	Pudukkottai	17.0	20.0	25.6
11	Ramanathapuram	17.1	20.0	25.7
12	Thoothukudi	17.2	20.1	25.8
13	Thirunelveli	17.2	20.2	25.8
14	Kanyakumari	17.2	20.2	25.8

3.5 Land Use Land Cover Assessment of Tamil Nadu - 2022

The land use land cover of coastal districts of Tamil Nadu was done for the period 2022 using Landsat high-resolution image, Google Earth, and Google Maps. The accuracy assessment of land use classification was done using ERDAS Imagine software. To calculate the accuracy 95 Ground Control points were generated using a stratified random sampling method.

The land use classification conducted in the coastal districts of Tamil Nadu revealed that agricultural land use dominates, accounting for approximately 70.49% of the total area. Other prominent land uses include water bodies, Built-up land (Rural), forests, wastelands, and Built-up land (Urban), which cover approximately 9.10%, 5.73%, 4.80%, 2.46%, and 2.34% of the area, respectively (Figure 19). In addition, specific coastal components such as mangroves, breakwaters, saltpans, lagoons, creeks, mudflats, and swamps were highlighted in the land use assessment for vulnerability assessment purposes. The total area of lagoons, creeks, mudflats, and swamps covered approximately 619.05 km^2, while saltpans occupied 192.10 km^2. Mangroves covered an area of 83.26 km^2, and breakwaters and other coastal protection structures encompassed 0.90 km^2 (Table 7).

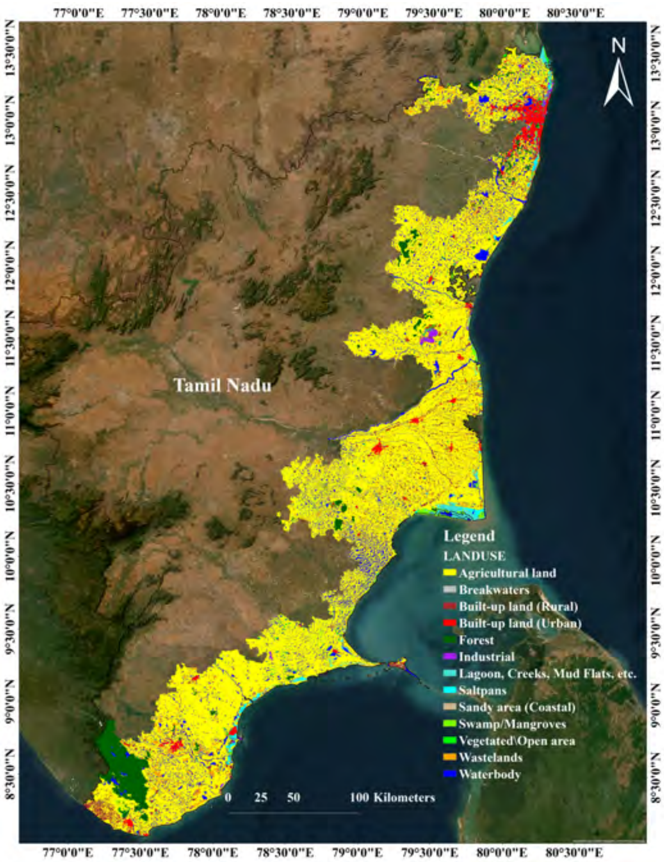


Figure 19 Land Use Land Cover of Tamil Nadu.

Table 7. Land Use Land Cover of Coastal districts of Tamil Nadu - 2022

S. No.	LANDUSE	Area sq.km	Area %
1	Built-up land (Urban)	970.11	2.34
2	Built-up land (Rural)	2372.71	5.73
3	Vegetated\Open area	814.80	1.97
4	Industrial/ Mining area	283.37	0.68
5	Forest	1989.96	4.80
6	Lagoon, Creeks, Mud Flats, Swamp	619.05	1.49
7	Saltpans	192.10	0.46
8	Waterbody	3773.06	9.10
9	Sandy area (Coastal)	112.39	0.27
10	Wastelands	1017.57	2.46
11	Agricultural land	29210.93	70.49
12	Mangroves	83.26	0.20
	TOTAL	41440.25	100.00

3.6 Impact on LULC due to SLR induced Coastal Inundation

With the acceleration of sea level rise, the likelihood of risks from various coastal processes rises. This includes increased occurrences of episodic flooding and permanent inundation in low-lying areas vulnerable to high tides, as well as the erosion of ecologically important habitats like beaches, coastal wetlands, lagoons, and creeks (Report: California Sea Level Rise Guidance, 2024). The inundation model using ArcGIS indicates that nearly 347.34 km^2 and 357.48 km^2 area would be under the threat of inundation for an average SLR of 19.71 cm and 24.97 cm as per SSP2-4.5 SLR projections, respectively (Figure 20). The district-wise inundated area calculated results revealed that the Tiruvarur and Nagapattanam districts are highly vulnerable to SLR risks, followed by Thiruvallur, Tanjavur, Ramanathapuram, Chengalpattu, Thoothukudi, and Chennai districts. Nearly 117.9 km^2 and 103.5 km^2 areas would be inundated in the Tiruvarur and Nagapattanam districts, respectively, under the SSP2 4.5 scenario (Figure 10). However, the high inundation area projected in Thiruvarur and Nagapattanam districts is due to the Muthupet lagoon area, which is one of the low-lying areas of the Tamil Nadu coast having elevation of <1m.

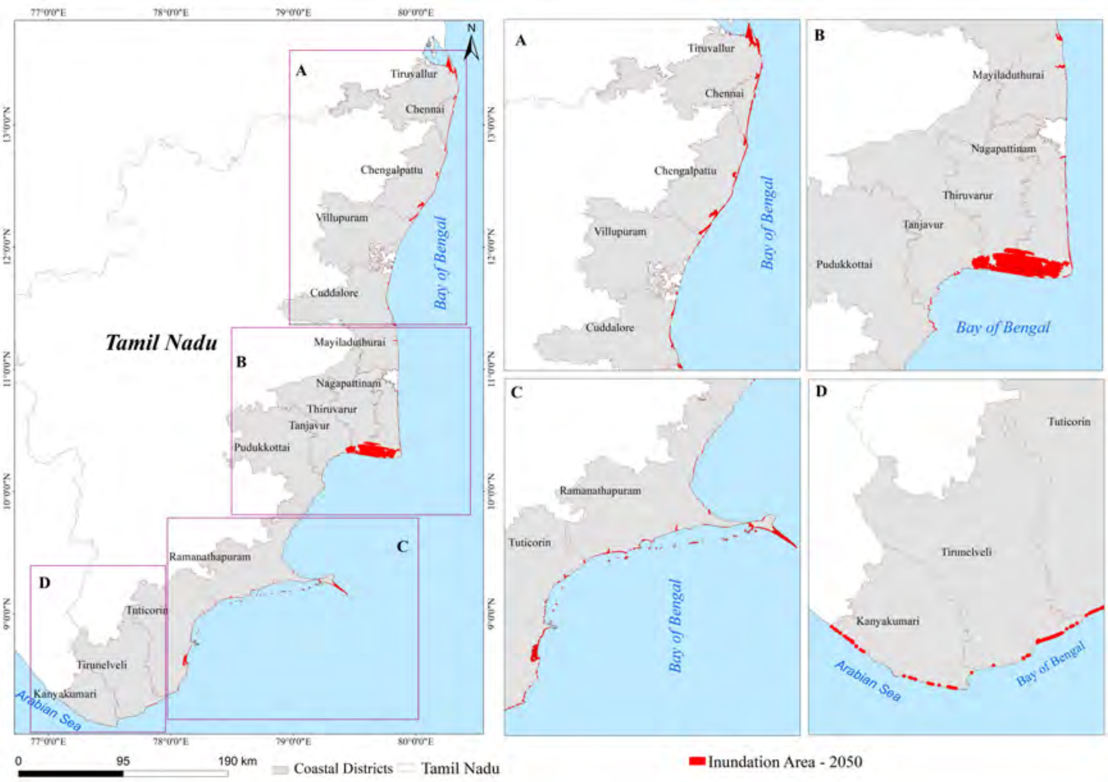


Figure 20 Coastal inundation of Tamil Nadu due to Sea Level Rise - SSP 2-4.5 scenario

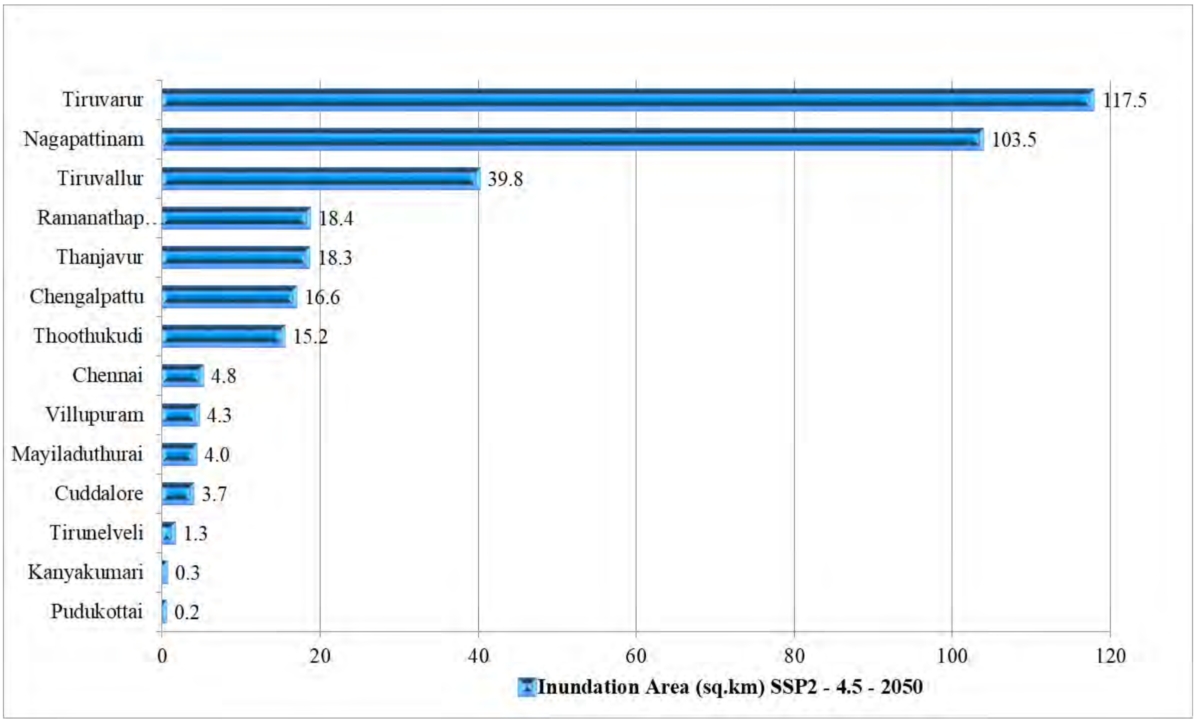


Figure 21 Inundation (sq.km) due to SLR at Coastal districts of Tamil Nadu – SSP 2-4.5 – 2050

3.6.1 Impact of coastal Inundation on Land use

The impact of coastal inundation on various types of land uses was assessed by overlaying the inundation data with land use classifications. The findings reveal that the land use categories of Lagoon, Creeks, mudflats, and swamps would be the most affected by coastal inundation (Figure 22). Approximately 231 km^2 of this area is projected to be inundated due to rising sea levels by 2050 under the SSP2 4.5 scenario. Following closely behind are water bodies, saltpans, and agricultural land, with respective areas of 49.1 km^2, 28.6 km^2, and 20.1 km^2 expected to be impacted. Moreover, sandy beaches and mangroves are at risk from sea level rise, with approximately 8.6 km^2 and 6.5 km^2 of area respectively facing potential flooding.

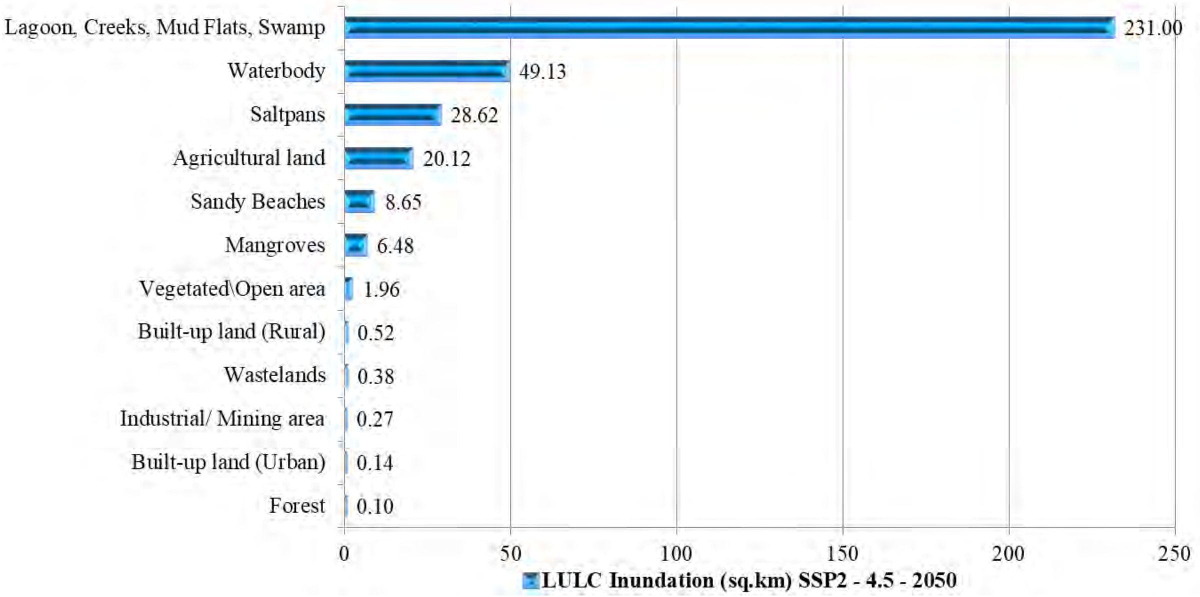


Figure 22 Impact of coastal inundation on different land use of Tamil Nadu

3.7 Shoreline Change Assessment of Tamil Nadu for the period of 1992-2022

A shoreline is defined as the location of the soil-water interface at a particular time, i.e., the contact between the land and water surface (Guariglia et al., 2006; Alesheikh et., 2008). The position and structure of shorelines are influenced by several spatial and temporal scales, where water level motions from waves and tides to relative sea-level change drive episodes of erosion and accretion (Burningham et al., 2020). Shoreline change analysis is an important part of coastal management, as it helps to monitor how changes in the environment are influencing shoreline habitats and ecosystems.

Tamil Nadu, located on India's south-eastern coast, has an extensive coastline of 1,076 km, which accounts for more than 13% of India's entire coast. It is the second largest coastline of the coastal states situated on the mainland of India. The Shoreline Change Assessment was carried out for the period of 30 years (1992-2022) using multi-temporal satellite images such as Landsat (TM, ETM+) and LISS IV data (Table 8). The six historical shorelines were manually digitized on-screen by applying visual interpretation techniques in ArcGIS software (Mageswaran et al., 2015; Kankara et al., 2014) from the year of 1992 to 2022. The Landsat images are collected from 1992 to 2016 at free of cost from USGS Earth Explorer https://earthexplorer.usgs.gov/ and for 2022 Resourcesat 2A LISS – IV data purchased from NRSC.

Table 8. Data Used for Shoreline Change Assessment

S.No	Satellite/sensor	Pixel Size (m)	Sources
1	Landsat 5 TM	30	USGS
2	Landsat 7 ETM+	30	USGS
3	Landsat 5 TM	30	USGS
4	Landsat 7 ETM+	30	USGS
5	Landsat 7 ETM+	30	USGS
6	Resourcesat 2A LISS – IV	5.8	NRSC - INDIAN

The shoreline change rate is classified as 7 classes mentioned in the table based on *Kankara et.al.,2014, 2015., selvan et al., 2020*.

Table 9. Classification of Erosion and Accretion

Classification	Rate (m/year)	Colour schemes
High Erosion	< -5.0	
Moderate Erosion	-5.0 to -3	
Low Erosion	-3.0 to -0.5	
Stable	-0.5 to 0.5	
Low Accretion	0.5 to 3.0	
Moderate Accretion	3.0 to 5.0	
High Accretion	>5.0	

The average erosion rates of Tiruvallur, Cuddalore, and Mayiladuthurai districts are 3.66, 2.86, and 2.71 m/year, respectively, indicating that these districts experienced high erosion, while Tirunelveli, Pudukkottai, and Villupuram districts experienced low erosion rates 0.51, 0.7, and 0.79 m/year, respectively (Table 10). The average accretion rates of Tiruvallur, Thuthookudi, and Nagapattinam districts are 6.6, 2.86, and 2.72 m/year, respectively, indicating that these districts experienced high accretion, while Villupuram, Pudukkottai, and Chennai districts experienced low erosion rates 0.62, 0.82, and 0.89 m/year, respectively.

Table 10. The average rate of erosion and accretion along Tamil Nadu

District Name	Average Erosion rate (m/year)	Average Accretion rate (m/year)
Tiruvallur	3.66	6.6
Chennai	1.25	0.89
Chengalpattu	0.93	0.95
Villupuram	0.79	0.62
Cuddalore	2.86	2.3
Mayiladuthurai	2.71	1.13
Nagapattinam	2.03	2.72
Tiruvarur	1.33	2.51
Tanjavur	0.83	1.23
Pudukkottai	0.7	0.82
Ramanathapuram	1.2	1.9
Thuthookudi	2.01	3.02
Tirunelveli	0.51	1.68
Kanyakumari	1.03	1.59

The districts such as Tiruvallur, Mayiladuthurai, Ramanathapuram, Thuthookudi, Nagapattinam, and Cuddalore experienced high erosion. Moderate erosion was observed in the Mayiladuthurai, Cuddalore, Thuthookudi, Ramanathapuram, and Nagapattinam. Low erosion is dominant in some districts, i.e., Ramanathapuram, Chengalpattu, Kanyakumari, and Thuthookudi (Figure 24). In terms of accretion, the districts of Thoothukudi, Ramanathapuram, Tiruvallur, Nagapattinam, and Tirunelveli experience high accretion. On the other hand, Thoothukudi, Nagapattinam, Cuddalore, and Ramanathapuram districts were observed with moderate accretion (Table 11). Low accretion is dominant in Thuthookudi, Ramanathapuram, Nagapattinam, Tirunelveli, Thanjavur, and Cuddalore districts.

Table 11 Shoreline Change Assessment of Tamil Nadu – 2022

S. No	Districts	Coast Length in Km	Coast Length in Km						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	Tiruvallur	34.52	6.87	2.16	8.25	7.79	3.74	0.67	5.04
2	Chennai	39.51	-	2.12	9.71	19.46	7.72	0.41	0.09
3	Chengalpattu	74.58	-	1.64	42.21	20.02	9.69	1.02	-
4	Villupuram	33.69	-	0.46	12.87	15.56	4.79	-	-
5	Cuddalore	41.50	1.82	4.69	5.80	5.42	16.21	6.30	1.26
6	Mayiladuthurai	49.77	3.69	5.49	19.90	11.07	8.73	0.89	-
7	Nagapattinam	81.90	1.75	4.26	19.97	11.38	32.31	7.79	4.43
8	Tiruvarur	22.44	-	0.45	2.18	7.19	7.41	2.27	2.94
9	Thanjavur	43.27	-	0.85	7.26	15.56	17.22	1.40	0.98
10	Pudukkottai	43.55	0.28	0.05	14.55	21.38	7.13	0.16	-
11	Ramanathapuram	275.71	2.28	4.34	96.18	131.06	32.37	3.26	6.22
12	Thuthookudi	118.88	1.98	4.48	21.63	28.70	41.52	12.02	8.54
13	Tirunelveli	53.10	-	-	6.04	21.88	19.63	1.97	3.58
14	Kanyakumari	71.28	0.04	0.44	38.48	22.41	7.58	0.96	1.37
Total		983.69	18.72	31.44	305.02	338.89	216.05	39.11	34.45

The results obtained from the Linear Regression Rate analysis show that within 30 years (1992–2022), about 36 % of the coast experienced erosion, 30 % of the shoreline experienced accretion and 34% remained stable (Figure. 23).

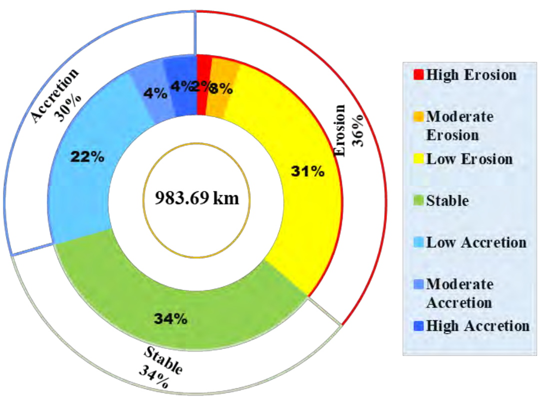


Figure 23 Shoreline Change Assessment of Tamil Nadu – 2022

3.7.1 Identification of Eroding Hotspots and Accretion Locations

The results are based on the Linear Regression Rate for the time period of 1992 to 2022. The eroding hotspots are identified based on the erosion rate ≥ 2.5m/yr. The hotspot locations have the limitations of their time domain and satellite data (NSAS Report). The accretion locations are identified based on the accretion rate ≥ 2.5m/yr (Figure 24).

Figure 24 Shoreline Change Assessment of Tamil Nadu

3.7.2 Shoreline Status of Tamil Nadu

Based on the Comprehensive Shoreline Protection Management Plan for Entire Tamil Nadu Coast submitted by IIT Madras to Dept. of Environment, Govt. of Tamil Nadu. Various organizations, including the Public Works Department (1978-2004), Space Application Centre (ISRO) (1989-2004), Indian Institute of Technology Madras (2004-2015), and National Centre for Coastal Research (1990-2018), provided the status of shoreline change results. Along with this, the shoreline change assessment for the period of 1992-2022 was conducted by the CCCDM.

These studies are utilized to analyze the periodic erosion and accretion of the Tamil Nadu coast. There are 24 locations covering 14 coastal districts in Tamil Nadu, from Ennore in Tiruvallur district to Erayumanthurai in Kanyakumari district (Table 12). It is observed that Ennore, Cuddalore, Poompuhar, Rameshwaram, Manakkudi, Manavalakurichi, and Midalam experienced consistent erosion from 1978 to 2022. Further detailed modeling studies are required for these locations to facilitate better community adaptation.

Table 12. Historical Shoreline Change Assessment Result status

S.No	Latitude	Longitude	Location	PWD (1978-2004)	SAC (1989-2004)	IIT (2004-2015)	NCCR (1990-2018)	CCCDM (1992-2022)
1	13°12'49.68"N	80°19'31.09"N	Ennore	Erosion	Erosion	Accretion/stable	Erosion	Erosion
2	13°3'53.64"N	80°17'16.81"N	Royapuram	Erosion	Erosion	Accretion/stable	Accretion	Accretion
3	13°3'19.07"N	80°17'3.84"N	Marina	Accretion/stable	Accretion/stable	Accretion/stable	Accretion	Accretion
4	13°1'27.12"N	80°16'43.68"N	Foreshore estate	Accretion/stable	Accretion/stable	Accretion/stable	Stable	Stable
5	12°47'25.08"N	80°15'8.27"N	Kovalam	Erosion	Erosion	Erosion	Accretion	Accretion
6	12°37'9.12"N	80°11'54.61"N	Mahabalipuram	Erosion	Erosion	Erosion/stable	Erosion	Stable
7	11°44'23.28"N	79°47'13.57"N	Cuddalore	Accretion/stable	Erosion	Erosion	Erosion	Erosion
8	11°9'34.2"N	79°51'21.97"N	Poompuhar	Erosion	Erosion	Erosion	Erosion	Erosion
9	11°1'43.32"N	79°51'20.87"N	Tranquebar	Erosion	Erosion/stable	Erosion/stable	Erosion	Stable
10	10°44'51"N	79°51'3.59"N	Nagapattinam	Erosion/stable	Accretion/stable	Erosion	Erosion	Stable
11	10°40'29.28"N	79°51'11.89"N	Velankanni	Erosion	Accretion/stable	Erosion	Stable	Stable
12	10°17'45.6"N	79°52'37.2"N	Point calimere	Accretion/stable	Accretion/stable	Accretion/stable	Accretion	Accretion
13	10°0'49.32"N	79°13'54.47"N	Ammapattinam	Accretion/stable	Accretion/stable	Accretion/stable	Stable	Stable
14	9°16'59.99"N	79°19'0.13"N	Rameshwaram	Erosion	Erosion/stable	Erosion	Erosion	Erosion
15	9°13'40.26"N	78°47'9.97"N	Keelakarai	Erosion/stable	Erosion/stable	Erosion/stable	Stable	Erosion
16	8°29'40.88"N	78°7'42.96"N	Tiruchendur	Erosion/stable	Accretion/stable	Erosion/stable	Erosion	Accretion
17	8°22'16.79"N	78°3'48.6"N	Manappad	Accretion/stable	Accretion/stable	Accretion/stable	Stable	Stable
18	8°5'23.57"N	77°28'40.43"N	Manakkudi	Accretion/stable	Accretion/stable	Erosion	Erosion	Erosion
19	8°5'53.59"N	77°25'58.44"N	Pallam	Erosion/stable	Accretion/stable	Accretion/stable	Erosion	Stable
20	8°7'26.61"N	77°18'50.77"N	Muttom	Accretion/stable	Accretion/stable	Accretion/stable	Erosion	Stable
21	8°8'44.63"N	77°18'3.25"N	Manavalakurichi	Erosion/stable	Erosion/stable	Erosion	Erosion	Erosion
22	8°10'21.14"N	77°15'16.56"N	Colachel	Erosion/stable	Erosion/stable	Accretion/stable	Accretion	Accretion
23	8°12'10.76"N	77°12'50.39"N	Midalam	Erosion/stable	Erosion/stable	Erosion	Erosion	Erosion
24	8°14'37.46"N	77°9'47.88"N	Erayumanthurai	Erosion/stable	Erosion/stable	Erosion	Erosion	Stable

Source: Report: DOE-IIT Madras, 2016; NCCR, 2022, CCCDM, 2023

3.7.3 Land Loss and Land Gain Assessment of Tamil Nadu for the period of 1992-2022

The land loss and land gain of the area are quantified using geospatial techniques. The satellite images of the year 1992 and 2022 are utilized in the assessment (Markose et al., 2016). The land loss and land gain assessment for the state is estimated by applying geospatial techniques (Figure 25). The historical satellite images are involved in this assessment. The land loss and gain assessment details are given in the hectares at district-wise.

The Ramanathapuram district has the highest land loss of 558.16 ha, followed by Mayiladuthurai, Nagapattinam, and Tiruvallur (Figure 26). The Thoothukudi district has the highest land gain of 285.55, followed by Tirunelveli, Tiruvarur.

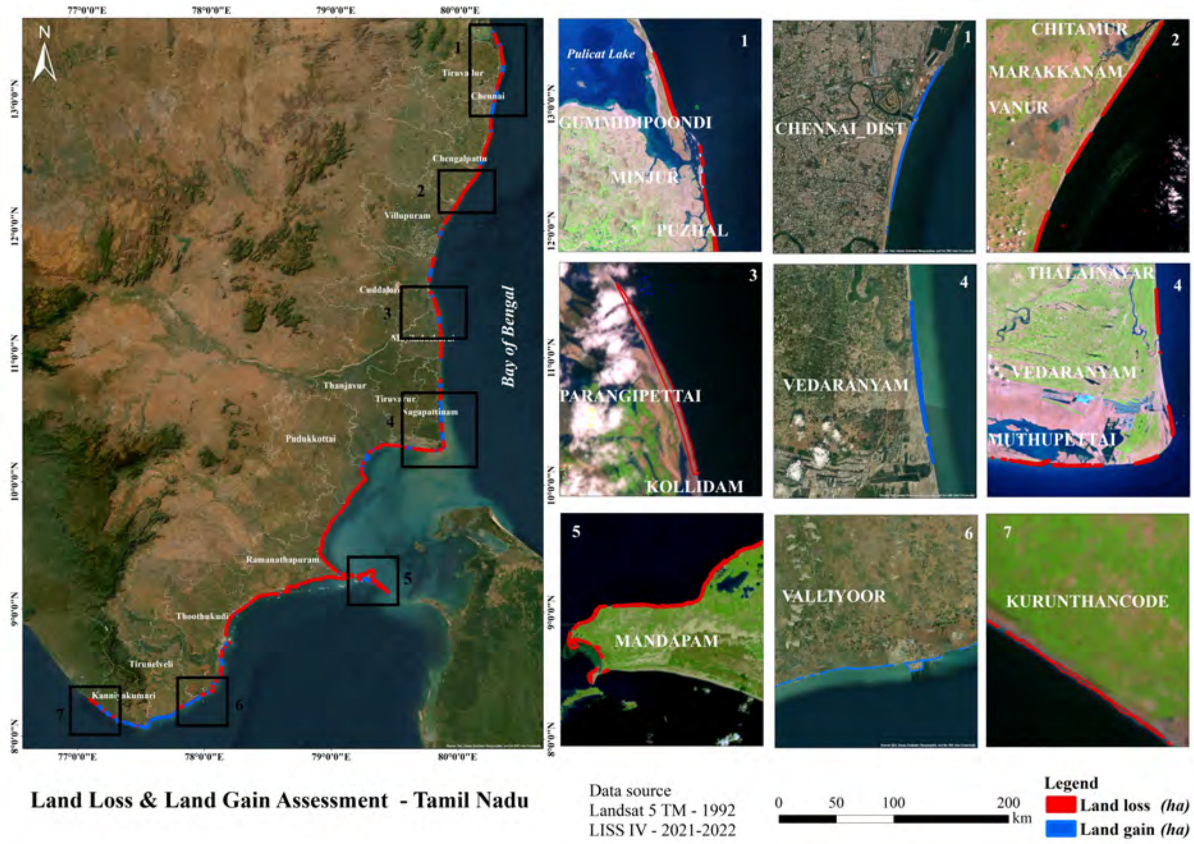


Figure 25 Land Loss and Land Gain Assessment of Tamil Nadu - 2022

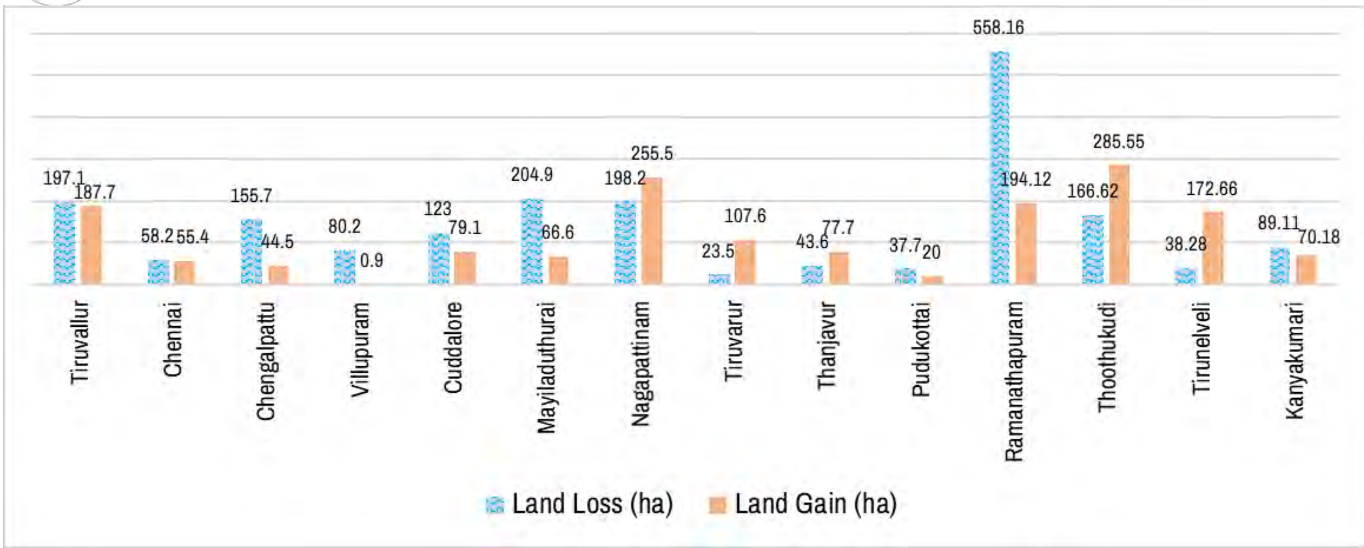


Figure 26 District wise Land Loss and Land Gain Assessment of Tamil Nadu

3.8 Cyclone frequency analysis of Tamil Nadu for the period of 1891-2022

Tropical cyclones are developed due to the intense low-pressure areas of the earth's atmosphere-coupled system (NDMA). Cyclone is the tropical weather systems in which winds equal or exceed the minimum of 34 knot (62 kmph). The Indian classification of the cyclones by IMD is mentioned in the table 13.

Table 13. Indian classification of cyclonic disturbances by IMD

Type	Wind speed in Km/h	Wind speed in knot
Low pressure (L)	< 31	< 17
Depression (D)	31-49	17-27
Deep Depression (DD)	50-61	28-33
Cyclonic storm (CS)	62-88	34-47
Severe cyclonic storm (SCS)	89-118	48-63
Very severe cyclonic storm (VSCS)	119-221	64-119
Super cyclonic storm (Sup.CS)	>222	>120

The North Indian Ocean generates about 7% of global cyclones with (5 to 6 cyclones per year). The frequency is very less over the west Arabian Sea mainly due to colder Sea surface temperature (SST). The genesis of cyclonic disturbances varies with respect to season, mostly takes place in lower latitudes in association with inter-tropical convergence zone (ITCZ) during pre-monsoon (March-May) and post-monsoon (October-December) seasons, it occurs over northerly latitude during monsoon season (June-September).

The Bay of Bengal TCs more often strike Odisha-West Bengal coast in October, Andhra coast in November and the Tamil Nadu coast in December. The northern coastal districts of Tamil Nadu are more vulnerable to cyclones with varying frequency and intensity. To develop coastal vulnerability, it is necessary to identify the coastal hazards i.e., cyclones associated with gale winds, extreme rainfall, and storm surges. This study identified the districts that are prone to frequent cyclones by collecting the cyclone track information from the India Metrological Department, Joint Typhoon Warning Centre (JTWC) and International Best Track Archive for Climate Stewardship (IBTrACS).

A severe cyclonic storm (SCS) is defined as a storm having a wind speed greater than 48 knots. The frequency analysis was carried out for the SCS using IMD e atlas data. The data is available for the period of (1891 to 2022). There are a total of 33 SCS that occurred during the period of (1891 to 2022). Notably, the year 1966 has 3 SCS, and 1964 and 2000 have 2 SCS.

During the months of November and December (northeast monsoon), the SCS is making landfall in the coastal districts of Tamil Nadu. The following are the districts that are vulnerable due to the frequent landfall of severe cyclonic storms. There are 14 coastal districts in Tamil Nadu, nine of which are prone to cyclone landfall, as mentioned in the table 14. Districts such as Chengalpattu, Cuddalore, Nagapattinam, and Villupuram are more vulnerable due to more than 2 SCS-made landfalls (Table 14).

Table 14. Districts Vulnerable to Severe Cyclonic Storm

S. No	Districts	Number of SCS
1	Chennai	3
2	Chengalpattu	8
3	Villupuram	4
4	Cuddalore	6
5	Mayiladuthurai	1
6	Nagapattinam	5
7	Ramanathapuram	2
8	Tuticorin	1
9	Tirunelveli	2

3.8.1 Cyclonic storm frequency and year interval analysis

The overall cyclone data are collected from the India Meteorological Department. The analysis, such as frequency of the cyclonic storms and year interval between the cyclonic storms, are carried out for the year (1891-2022) (Figure 27). A total of 59 Cyclones made landfall in Tamil Nadu. It is observed during the years 1930 to 1935, 1941 to 1944, 1962 to 1967 except 1965, and from 1991 to 1996, except 1995, where there was a cyclonic storm ≥ 34 knots each year. Though the occurrence of a cyclonic storm is one per year, the frequency of events is observed at two-year intervals. After 2016, the event is occurring at the frequency of two-year intervals (Figure 28).

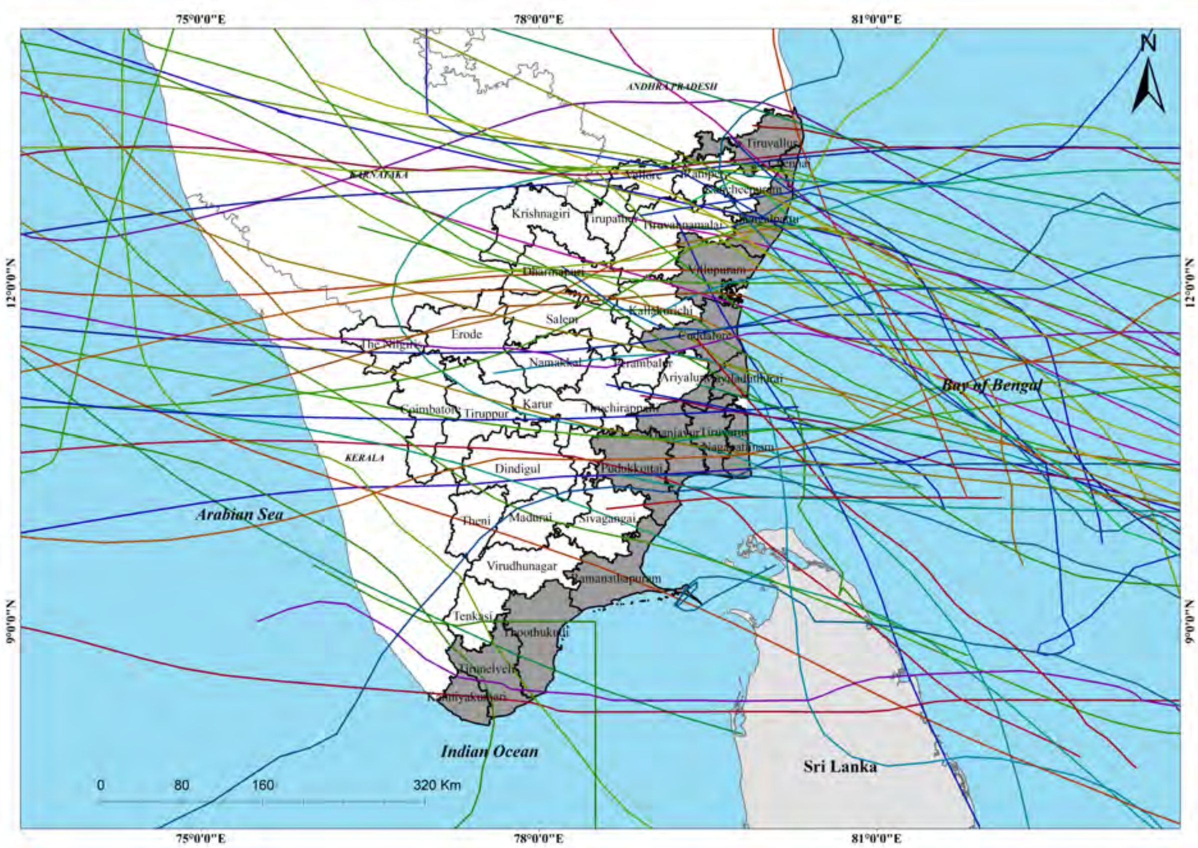


Figure 27 Overall Cyclonic Storm track of Tamil Nadu (1891-2022)

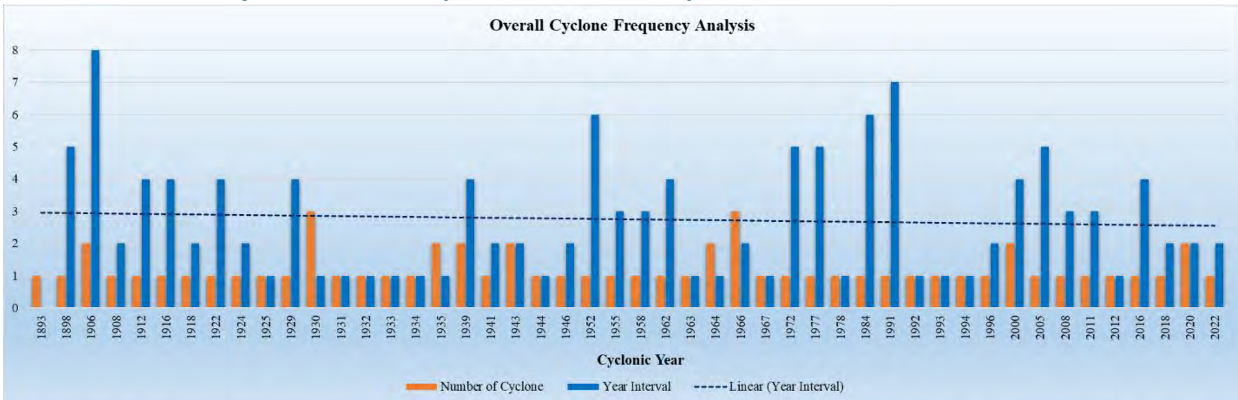


Figure 28 Overall Cyclonic Storm Frequency and Year Interval Analysis of Tamil Nadu (1891-2022)

3.8.2 Severe Cyclonic storm frequency and year interval analysis (1891-2022)

The Severe Cyclonic Storm data are collected from the India Meteorological Department. The analysis, such as frequency of the Severe cyclonic storms and year interval between the cyclonic storms, are carried out for the year (1891-2022). Since the mid-twentieth century (1951–2018), there has been a notable decrease in the annual frequency of tropical cyclones across the NIO basin. However, there has been a significant increase (+1 event per decade) in the occurrence of very severe cyclonic storms (VSCSs) during the post-monsoon season over the last two decades (2000–2018). The climate models indicate a projected intensification of tropical cyclones in the NIO basin throughout the twenty-first century Krishnan, et.al., 2020.

A total of 33 Severe Cyclonic Storms ≥ 48 knots each year made landfall in Tamil Nadu. Though the occurrence of a cyclonic storm is one per year, the frequency of events is observed at two-year intervals. During the period 1964, 1966, and 2000, more than one severe cyclonic storm occurred. After 2016, the event is occurring at the frequency of two-year intervals (Figure 29).

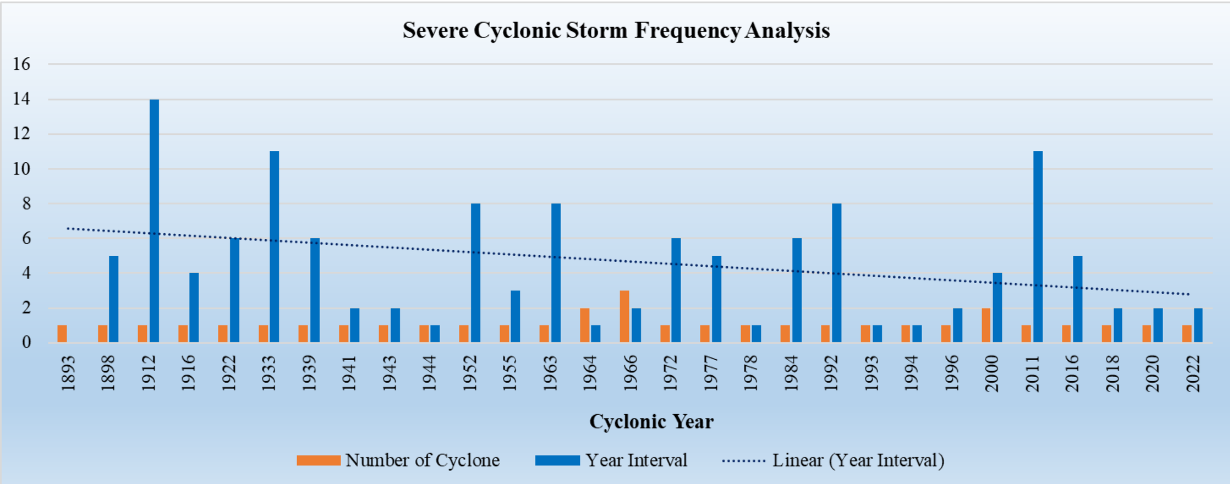


Figure 29 Severe Cyclonic Storm Frequency and Year Interval Analysis of Tamil Nadu (1891-2022)

3.8.3 Proximity to Severe Cyclonic Storm Track Analysis of Tamil Nadu (1891-2022)

The Severe Cyclonic Storms are identified using the IMD Cyclone e-atlas for the state of Tamil Nadu. The SCS tracks are collected from the IBTrACS. IBTrACS merges recent and historical tropical cyclone data from the World Meteorological Organization (WMO). The IBTrACS of subset basin North Indian data span from the 1840s to the present. The data includes the position, intensity (maximum sustained wind speed), radius of maximum winds, and environmental pressure (Knapp et al., 2010; Knapp et al., 2018). The proximity of an area to the cyclone track is based on the Table 15.

Table 15. Categorization of Vulnerability to the SCS track.

	Very Low	Low	Moderate	High	Very High
Distance to the track in Km	>70	70	50	25	10

The wind speed of Severe Cyclonic Storms is greater than 48 knots, and the area falling along the track of a severe cyclonic storm is highly prone to extreme winds and rainfall. So, the proximity analysis was done to identify the vulnerable locations based on the historical SCS tracks. The northern districts of Tamil Nadu, starting from Tiruvallur to Nagapattinam, are highly prone to frequent and intensified cyclonic storms (Figure 30).

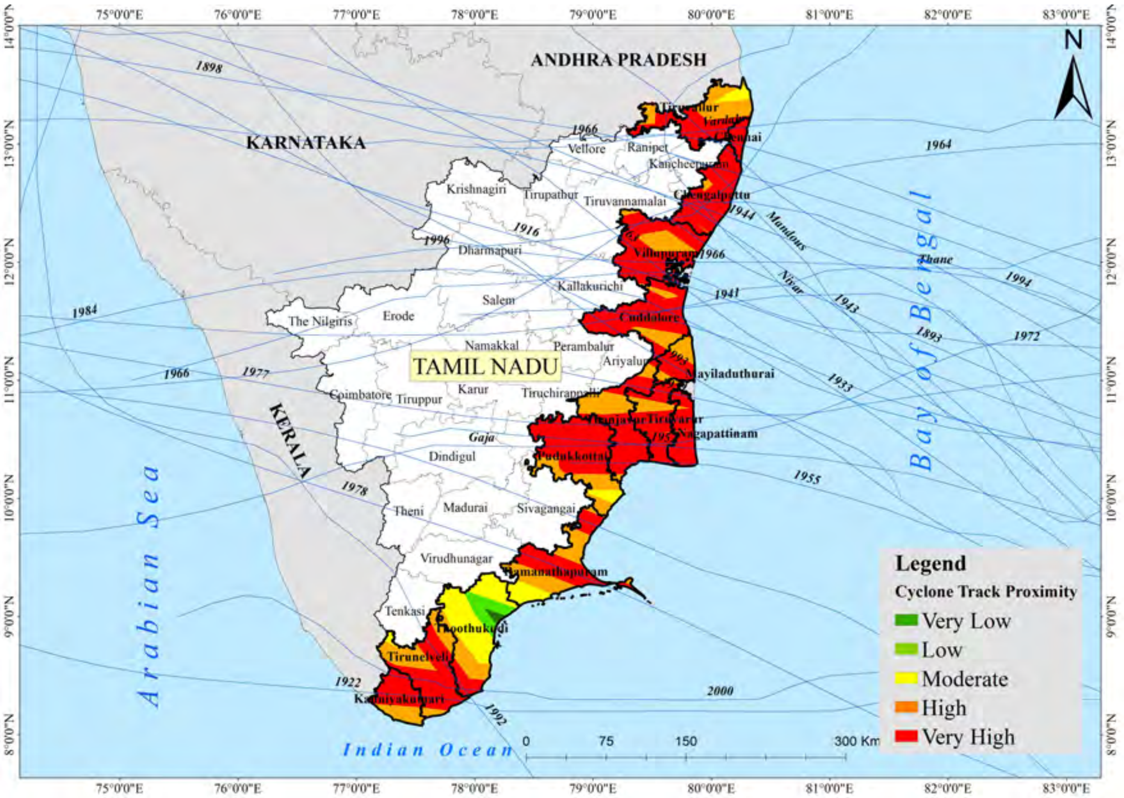


Figure 30 Proximity to cyclone track of Tamil Nadu

3.9 Coastal Hazard Index of Tamil Nadu

In context with, coastal hazards such as shoreline changes, Sea level rise, tropical cyclones, and storm surges has the potential to cause damage to, or loss of, coastal ecosystems, buildings, infrastructures and coastal communities (Table 16). In the present study, the following indicators in the table were taken for coastal hazard assessment. The coastal hazard index is calculated as the square root of the product of the ranked variables divided by the total number of variables (Hammar-Klose and Thieler, 2001; Kumar et al., 2010; Hossain et.al., 2022, Gornitz et.al., 1989, Gornitz et.al., 1991, Thieler et.al., 1999).

Table 16. Coastal Hazard Indicators

Variables	Very Low	Low	Moderate	High	Very High	Data Source	Reference
Shoreline Change Rate (m/yr)	> +2	+1 to +2	-1 to +1	-1 to -2	< -2	DSAS - Satellite Images	Ahmed et.al., 2022
Sea Level Rise (mm/yr)	≤ -1.1 Land Rising	-1.0 to 0.99 Land Rising	1 to 2.09 Within range of eustatic rise	2.1 to 4.0 Land Sinking	≥ 4.0 Land Sinking	Base Period (1916 - 2021) – PSMSL Near - century SimCLIM (2005-2050) – AR6	Gornitz et.al., 1991
Proximity To Cyclone Track (km)	>70	70	50	25	10	IMD, IBTracs	Malakar et.al., 2021

Coastline of Tamil Nadu is classified based on hazard indicators such as shoreline change rate, rising sea levels, and cyclones. The coastal hazard analysis reveals that the percentage of coastline of Nagapattinam, Chengalpattu, Chennai, and Tiruvarur districts are particularly highly susceptible to hazards, with over 60% of their coastlines falling into this category in base period and near century. The high hazard susceptibility in these districts is mainly due to shoreline changes and the impacts of cyclones. On the other hand, Tirunelveli, Pudukkottai, and Kanyakumari districts are classified as having low to moderate hazards category. Considering hazard indicators for the base period (1992 – 2022) and projections for the near century (2023- 2050), approximately 531 km of the Tamil Nadu coastline will be classified as high hazard-prone areas in base period, and 621 km of coastline under high hazard-prone areas in the near century (Table 17).

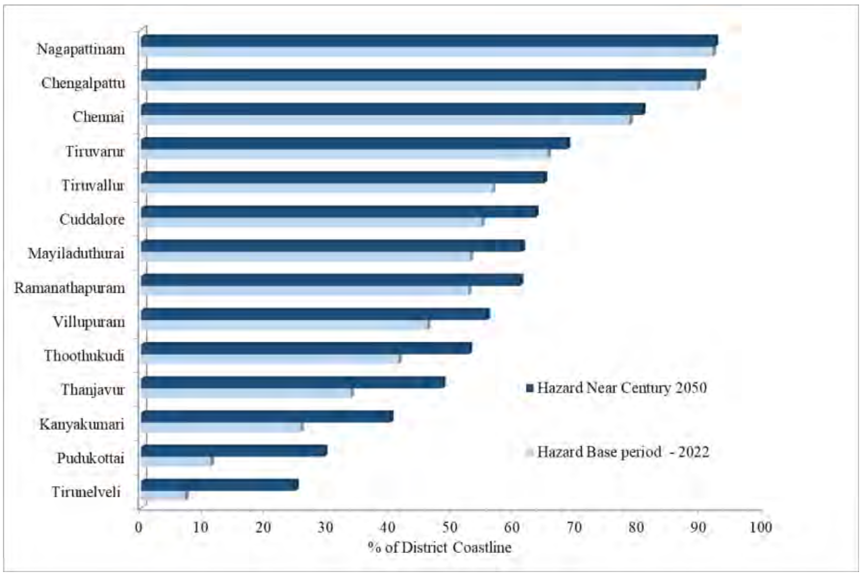


Figure 31 Percent of District Coastline under high – Very high Hazard Category (Baseline and Near Century) – Tamil Nadu

Table 17. Coastal Hazard Index of Coastal Length (km) of Tamil Nadu

District	Coast Length in km								
	Hazard Base Period				Hazard Near Century - 2050				District Length
	VL	L	M	H-VH	VL	L	M	H-VH	
Tiruvallur	0.7	1.7	16.4	24.3	0.5	1.4	13.3	27.9	43.2
Chennai	0.0	5.3	5.2	38.0	0.0	4.7	4.8	39.0	48.4
Chengalpattu	0.0	0.5	7.5	66.6	0.0	0.4	6.9	67.3	74.6
Villupuram	0.0	11.6	6.6	15.5	0.0	9.7	5.3	18.7	33.7
Cuddalore	1.9	6.1	11.2	23.1	1.4	5.1	9.1	26.8	42.3
Mayiladuthurai	0.1	16.0	7.8	26.7	0.1	13.3	6.3	30.9	50.5
Nagapattinam	0.0	2.8	4.1	76.7	0.0	2.7	3.9	77.0	83.5
Tiruvarur	0.2	1.8	6.1	15.3	0.2	1.6	5.6	16.0	23.4
Thanjavur	13.7	0.6	15.3	15.0	10.1	0.5	12.4	21.6	44.6
Pudukottai	12.3	13.0	14.2	5.0	9.1	10.8	11.5	13.1	44.6
Ramanathapuram	0.0	99.0	32.9	146.1	0.0	82.1	26.7	169.1	277.9
Thoothukudi	8.3	18.0	53.5	56.2	6.2	14.9	43.3	71.6	136.0
Tirunelveli	1.1	3.1	45.4	3.8	0.8	2.6	36.8	13.3	53.5
Kanyakumari	3.5	2.3	49.3	19.0	2.6	1.9	40.0	29.7	74.2
Total	42.0	181.8	275.4	531.2	31.1	151.7	225.7	621.9	1030.4

VL – Very Low, L – Low, M – Moderate, H-VH – High to Very High

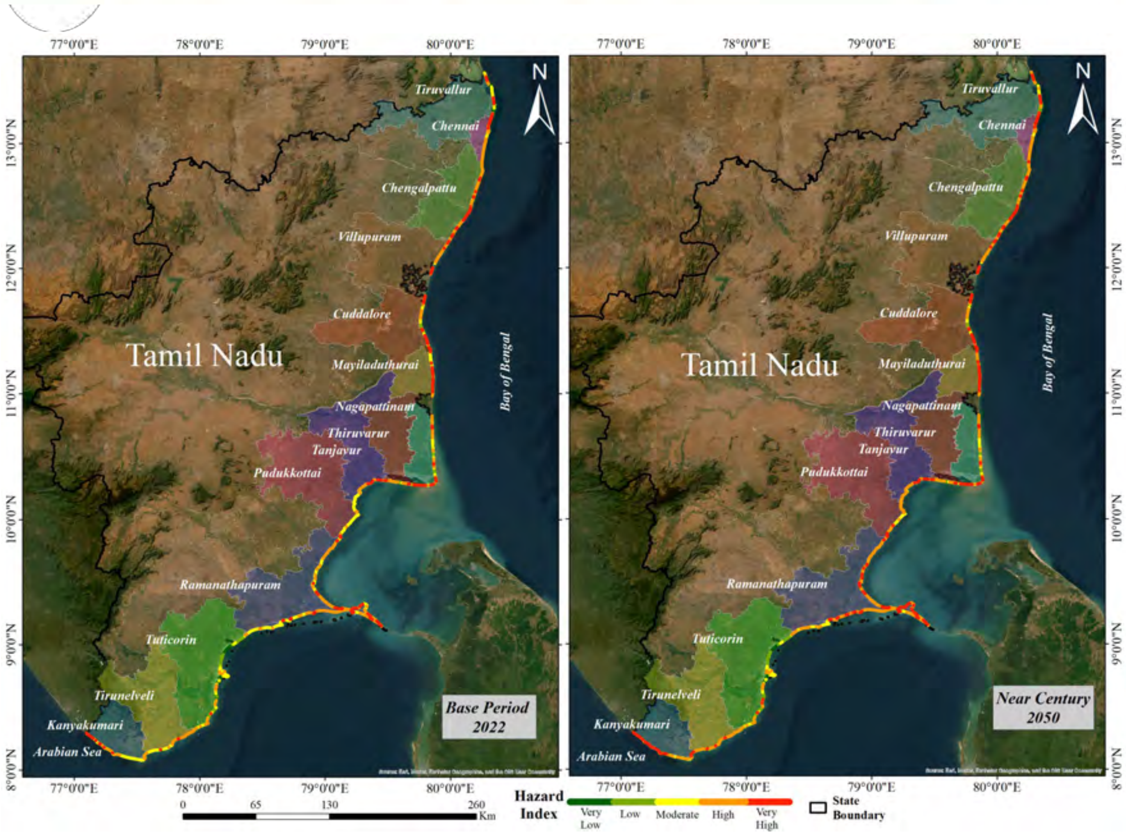


Figure 32 Hazard map of Tamil Nadu coast.

3.10 Coastal Vulnerability Index of Tamil Nadu

Coastal Vulnerability is the identification of coastal resources at risk due to coastal hazards. The coastal vulnerability index (CVI) presented here is the same as that used in Thieler and Hammar-Klose (1999) and is similar to that used in Gornitz et al., 1994, as well as to the sensitivity index employed by Shaw and others (1998). Once each section of coastline is assigned a vulnerability value for each specific data variable, the coastal vulnerability index (CVI) is calculated as the square root of the product of the ranked variables divided by the total number of variables (Hammar-Klose and Thieler, 2001; Kumar et al., 2010; Hossain et.al., 2022, Gornitz et.al., 1989, Gornitz et.al., 1991, Thieler et.al., 1999).

Table 18. Coastal Vulnerability Indicators

Variables	Very Low	Low	Moderate	High	Very High	Data Source	Reference
Coastal Elevation (m)	>8	6 to 8	4 to 6	2 to 4	<2	SRTM DEM	Ahmed et.al., 2022
Coastal Slope (%)	>4	3 to 4	2 to 3	1 to 2	<1	GEBCO	Present
Tidal Range (m)	<1	>1 to <2	>2 to <4	>4 to <6	>6	WX Tide 32	Mani Murali et.al., 2013
Significant Wave Height (m)	<1	>1 to <1.25	>1.25 to <1.4	>1.4 to <2.0	>2.0	INCOIS	Kumar et.al., 2010
Geomorphology	Cliffs, Rocky Coasts, Gullied Lands, Barren Lands	Dense Mangroves, Dense Vegetation, Wetlands, Mudflats, Tidal Flats, Marsh Vegetation	Sparsely Vegetated Coastal Plains, Sparse/Degraded Mangrove, Open/Vacant Lands, Wide Lagoons	Aquaculture, Salt Pans, Backwaters, Bays, Inundated Coasts, Narrow Lagoons, Creeks, Estuaries and Mangroves	Sandy Beach, Spit, Delta And Inhabited Coastal Plains	Bhukosh - Geological Survey Of India	Sahoo et.al., 2018
Electrical Cunductivity(EC) (µS/cm)	<100 Low Salinity	101-250 Low Salinity	251 – 750 Moderate Salinity	751 – 2250 High Salinity	>2250 Very High Salinity	TWAD BOARD-TamilNadu	Ravikumar et al., 2013

To assess the vulnerability of the Tamil Nadu coast to climate-related hazards such as sea level rise, inundation, and cyclones, the above-mentioned indicators have a significant role (Table 18). The Tamil Nadu coastal areas predominantly have low elevations and gentle slopes along Nagapattinam and Tiruvarur. The major geomorphological features are sandy beaches, estuaries, lagoons, creeks, and mudflats found along Tiruvallur to Tiruvarur. There are 42 tidal inlets found along the coast, which provide ecosystem services. The climate extremities severely affect the coastal communities and habitats of Tamil Nadu.

In Tamil Nadu, the coastal vulnerability assessment reveals that the majority of districts are categorized as high-vulnerability areas. Specifically, Chengalpattu, Nagapattinam, Tiruvarur, Chennai, Tiruvallur, Cuddalore, Ramanathapuram, and Thoothukudi districts have extensive coastlines, with more than 80% of their coastal areas falling into the high vulnerability category. The primary factors contributing to the high vulnerability in these districts include high salinity levels in coastal waters, significant wave height, and low-lying areas with gentle slopes. Out of the total 1030.4 km of coastline in Tamil Nadu, 839.6 km is categorized as being under very high vulnerability (Table 19).

Table 19. Vulnerability assessment of Coastal Districts of Tamil Nadu

District	Coast Length in km				
	Very Low	Low	Moderate	High - Very High	Total
Tiruvallur	0.1	2.2	2.3	38.5	43.2
Chennai	0.4	1.5	2.3	44.2	48.4
Chengalpattu	0.1	0.0	1.1	73.5	74.6
Villupuram	1.8	2.4	4.9	24.5	33.7
Cuddalore	0.4	3.6	2.7	35.7	42.3
Mayiladuthurai	0.2	3.1	10.3	36.9	50.5
Nagapattinam	0.3	0.1	2.3	80.8	83.5
Tiruvarur	0.0	0.0	1.1	22.3	23.4
Thanjavur	0.0	1.8	8.5	34.2	44.6
Pudukottai	0.3	3.0	6.1	35.2	44.6
Ramanathapuram	4.7	15.6	24.9	232.8	277.9
Thoothukudi	1.8	13.4	13.1	107.8	136.0
Tirunelveli	8.7	1.7	5.4	37.7	53.5
Kanyakumari	19.4	9.1	10.0	35.6	74.2
Vulnerability (TN)	38.2	57.6	95.0	839.6	1030.4

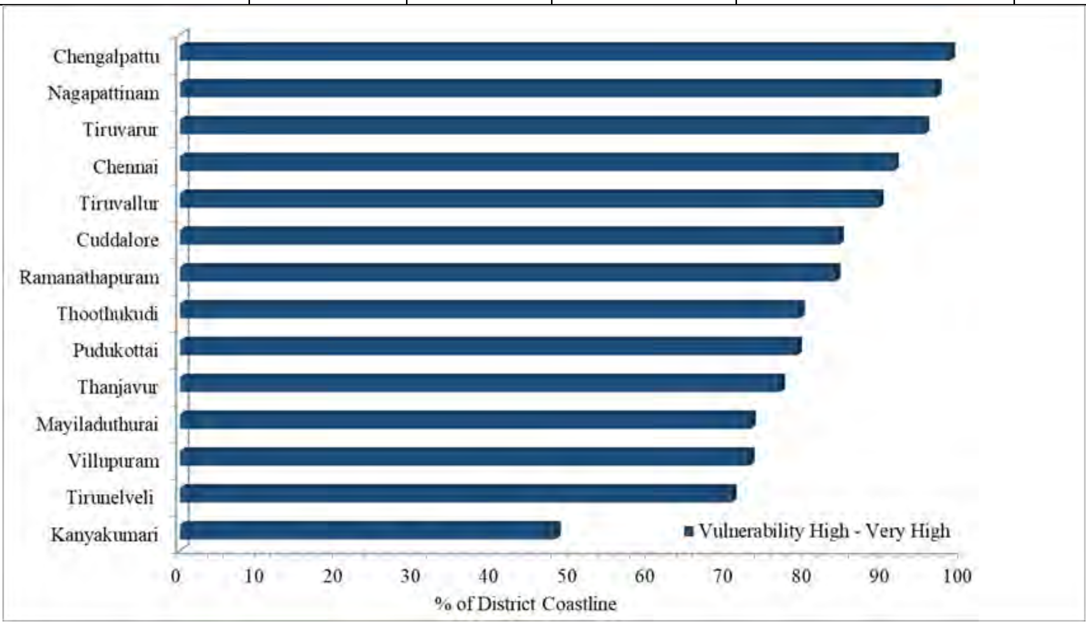


Figure 33 Percent of District Coastline under high – Very high Vulnerability – Tamil Nadu

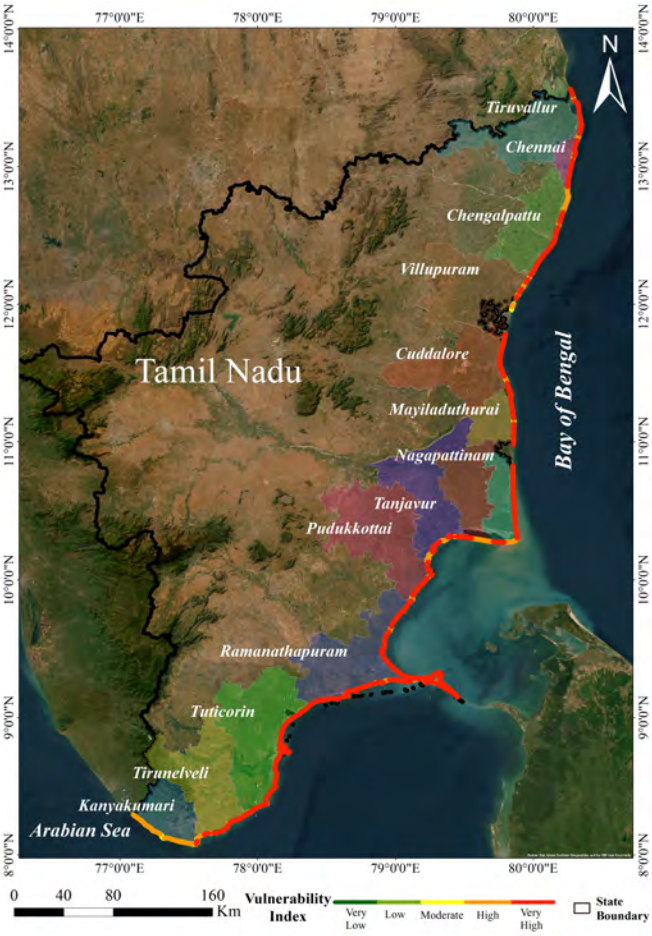


Figure 34 Coastal Vulnerability Index map of Tamil Nadu.

3.11 Coastal Exposure Index of Tamil Nadu

In this study, exposure indicators such as Land Use Land Cover and Road Networks are used to assess the coastal exposure index (Table 20). The study focused on the 500m coastal area from the 2022 shoreline and did not use socio-economic data such as population density, GDP, Literacy rate etc., due to its coarse resolution availability (IPCC-SROCC). Notably, in the coastal districts of Tamil Nadu, predominant land uses encompass 29,211 sq.km of Agricultural land, 3,773 sq.km of Water bodies, 2,373 sq.km of Rural Build-up land, 970 sq.km of Urban Build-up land, 192.1 sq.km of Salt pans, 112 sq.km of Sandy areas (Beaches), and 83 sq.km of Mangroves. Moreover, the road networks spanning within 250 meters from the shoreline are interlinked, totaling a length of 337 kilometers of the coastline. These indicators are crucial for understanding and dealing with coastal disasters and mitigation actions to reduce their impact.

Coastal zones are exposed to diverse natural hazards under a changing climate. Therefore, the design of coastal areas and infrastructure should prioritize addressing these challenges (Malliouri et al. 2017). The Coastal Exposure Index of Tamil Nadu indicates that the districts Kanyakumari, Chennai, and Cuddalore are the most effected districts expose to climate change, with more than 60% of their coastlines falling under high and very high category. The level of exposure is influenced by factors such as land use and infrastructure (Roads), particularly in the Chennai, Kanyakumari, and Cuddalore districts. Out of the total 1030.4 km of coastline in Tamil Nadu, 487.5 km is categorized as being under high to high exposure catogory (Table 21).

Table 20. Coastal Exposure Indicators

Variables	Very Low	Low	Moderate	High	Very High	Data Source	Reference
LULC	Wastelands	Breakwaters, Forests, Vegetated and Open areas	Water Bodies	Agriculture land	Built-Up Area (Rural and Urban), Industires, Lagoons, creeks, mudflats, swamp, Mangroves, salt pans, Ecologically Important areas, Sandy beaches	CCCDM, 2023	Present Study
Road Network	>1 km buffer	1 km buffer	750 m buffer	500 m buffer	250 m buffer	IRS, Anna University	Mani Murali et.al., 2013

Table 21. Exposure Assessment of Coastal Districts of Tamil Nadu

District	Coast Length in km				
	Very Low	Low	Moderate	High - Very High	Total
Tiruvallur	0.0	9.5	11.5	22.2	43.2
Chennai	0.2	1.2	10.2	36.8	48.4
Chengalpattu	13.5	22.6	20.5	18.0	74.6
Villupuram	4.9	8.2	8.4	12.1	33.7
Cuddalore	8.0	2.5	3.0	28.9	42.3
Mayiladuthurai	15.4	20.3	10.0	4.8	50.5
Nagapattinam	7.1	34.8	32.2	9.4	83.5
Tiruvarur	0.0	0.0	10.2	13.2	23.4
Thanjavur	0.0	11.6	17.7	15.3	44.6
Pudukottai	3.5	11.4	6.2	23.4	44.6
Ramanathapuram	38.2	48.0	51.8	140.0	277.9
Thoothukudi	10.9	31.6	23.9	69.5	136.0
Tirunelveli	3.0	9.9	10.1	30.5	53.5
Kanyakumari	0.0	3.9	6.7	63.6	74.2
Total	104.8	215.6	222.4	487.5	1030.4

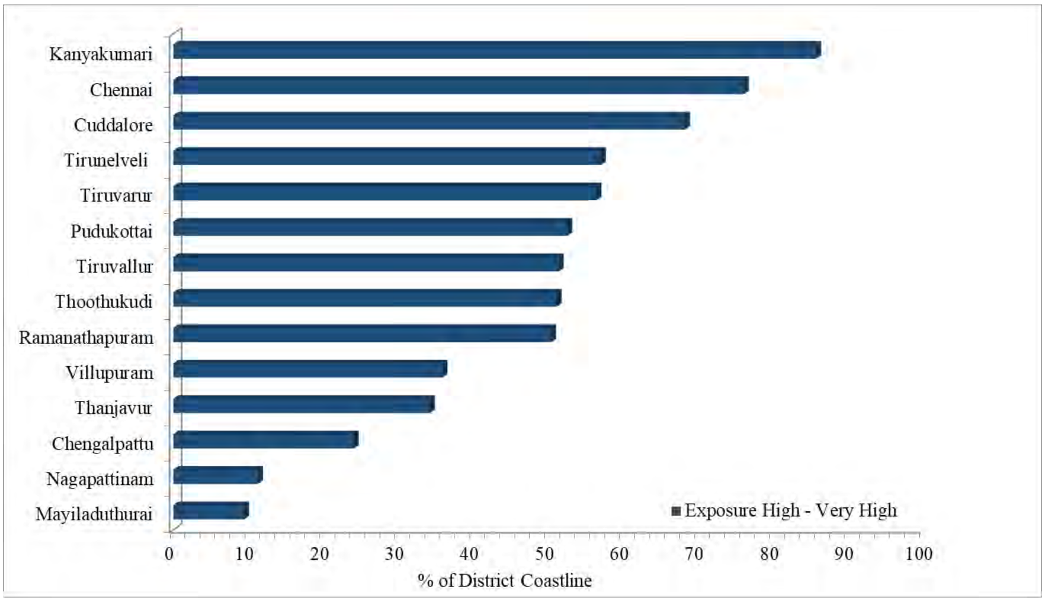


Figure 35. Percent of District Coastline under high – Very high exposure – Tamil Nadu

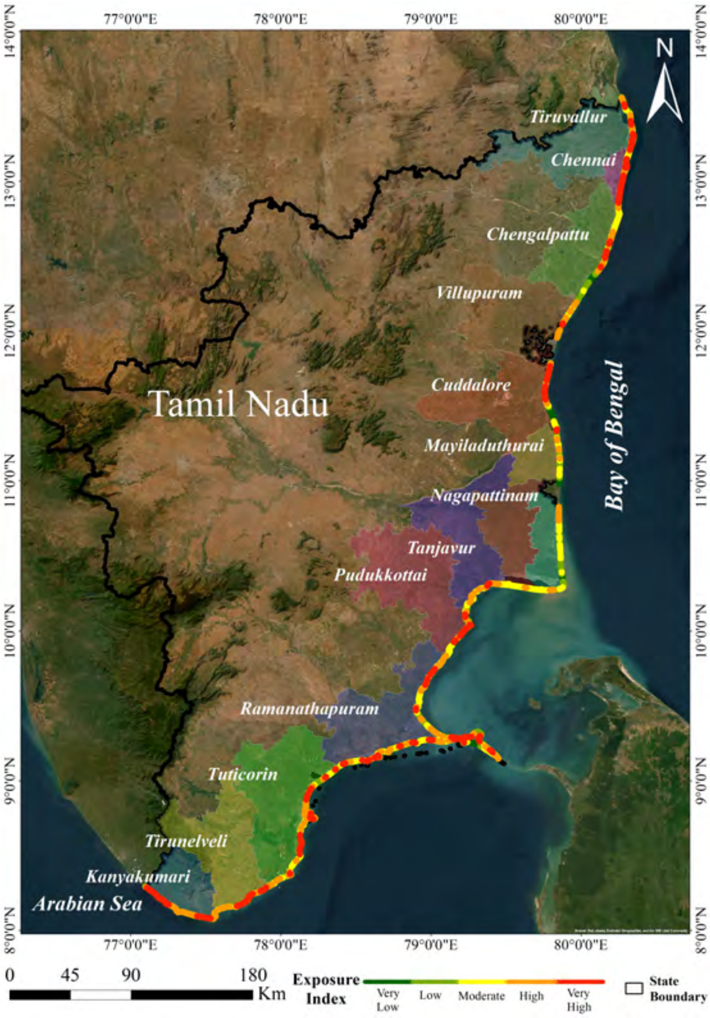


Figure 36. Exposure map of Tamil Nadu coast.

3.12 Coastal Risk Index of Tamil Nadu

Risk is defined as the potential for adverse consequences for human or ecological systems, recognizing the diversity of values and objectives associated with such systems. In the context of climate change impacts, risks result from dynamic interactions between climate-related hazards with the exposure and vulnerability of the affected human or ecological system (IPCC, 2022). The coastal Risk assessment framework for the Tamil Nadu coast was derived from the IPCC AR6 framework. The Coastal Risk Assessment was conducted by integrating Hazard, Vulnerability, and Exposure for both the base and future periods. The coastal Risk Index was formulated using the equation (1) (Hammar-Klose and Thieler, 2001; Kumar et al., 2010; Hossain et.al., 2022, Gornitz et.al.,1989, Gornitz et.al., 1991, Thieler et.al.,1999).

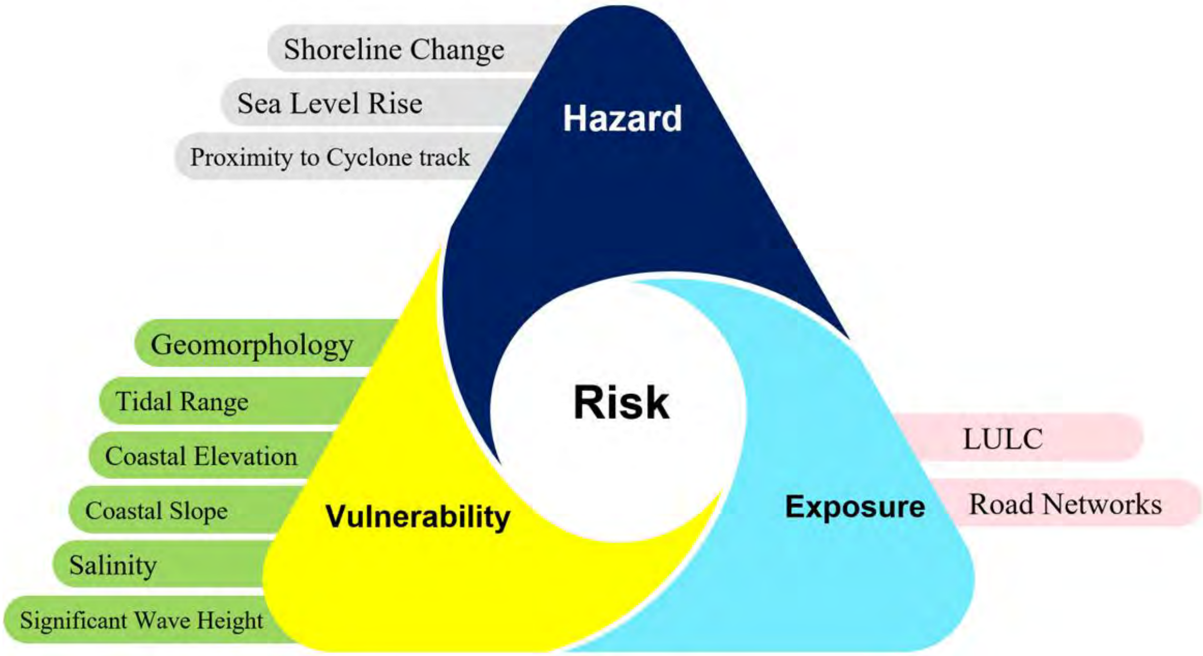


Figure 37 Coastal Risk Assessment Framework

Coastal Risk Index = Hazard*Vulnerability*Exposure (Malakar et al., 2021)

Coastal Risk Index = $\sqrt{\frac{(a*b*.........n)}{\text{No. of Indicators}}}$ (Hammar-Klose and Thieler, 2001; Kumar et al., 20 ….Eq (1)

Here, a,b, c,….. ,n = Indicators/ Variables.

The Coastal Risk assessment was conducted by integrating Hazard, Vulnerability, and Exposure for both the base period (1992- 2022) and near century (2023 – 2050). The assessment, conducted on a district level, revealed that the coastal districts, i.e., Tiruvarur, Nagapattinam, Chennai, Tiruvallur, Cuddalore, and Chengalpattu Districts, were particularly at high risk, with over 60% of their coastlines falling into high to very high risk category in base period and near century (Figure 39). This high risk can be attributed to factors such as coastal geomorphology, tidal range, significant wave height, slope, and exposure indicators, i.e., LULC and road network in these districts. On the other hand, the southern districts of Tirunelveli, Pudukottai, and Kanyakumari showed a relatively low risk to climate change. Out of the total 1030.4 km of coastline in Tamil Nadu, 493.9 km and 603.7 km is categorized as being under high to very high risk in base period and near century, respectively (Table 22).

Table 22. Summary of Risk Assessment of Coastal Districts of Tamil Nadu

District	Coast Length in km								
	Risk Base Period				Risk Near Century - 2050				District Length
	VL	L	M	H-VH	VL	L	M	H-VH	
Tiruvallur	1.9	7.5	9.2	24.5	1.6	5.5	9.2	26.9	43.2
Chennai	4.7	6.7	8.8	28.2	3.8	5.1	8.8	30.7	48.4
Chengalpattu	12.6	12.5	12.7	36.8	9.2	10.3	10.5	44.6	74.6
Villupuram	3.5	8.8	6.4	15.0	2.8	5.1	6.7	19.1	33.7
Cuddalore	4.7	9.5	6.2	21.9	3.2	4.9	8.0	26.2	42.3
Mayiladuthurai	9.3	3.2	14.0	24.0	5.1	4.2	11.2	30.0	50.5
Nagapattinam	1.8	12.2	9.5	60.1	1.5	6.3	12.3	63.4	83.5
Tiruvarur	0.9	1.9	1.8	18.8	0.7	1.5	2.0	19.1	23.4
Thanjavur	5.0	8.9	10.8	19.9	3.4	7.7	8.2	25.3	44.6
Pudukottai	10.9	2.5	14.5	16.7	8.0	2.1	11.8	22.7	44.6
Ramanathapuram	75.4	36.8	36.9	128.8	55.8	27.1	32.7	162.3	277.9
Thoothukudi	12.3	34.5	32.7	56.6	8.2	15.1	39.8	72.9	136.0
Tirunelveli	14.0	11.2	14.1	14.1	10.4	8.2	12.4	22.5	53.5
Kanyakumari	15.8	17.2	12.7	28.4	11.6	13.1	11.6	37.9	74.2
Total	172.8	173.4	190.3	493.9	125.2	116.3	185.2	603.7	1030.4

VL – Very Low, L – Low, M – Moderate, H-VH – High to Very High

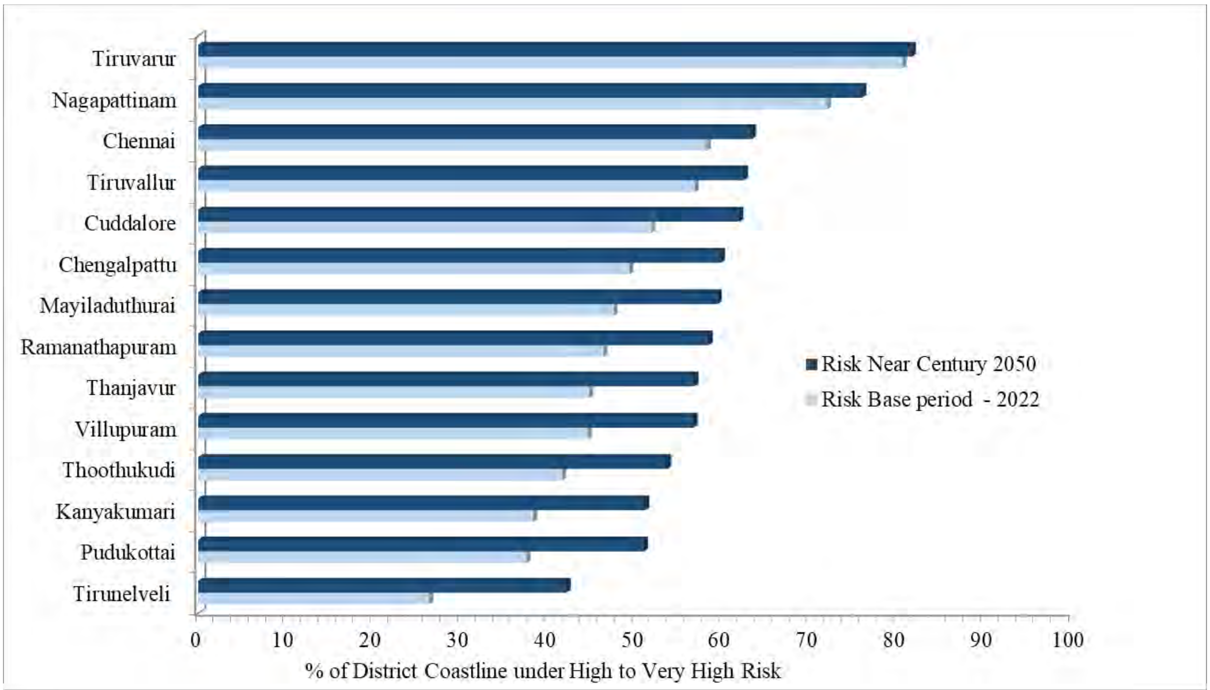


Figure 38 Percent of District Coastline under High – Very high Risk Category – Tamil Nadu

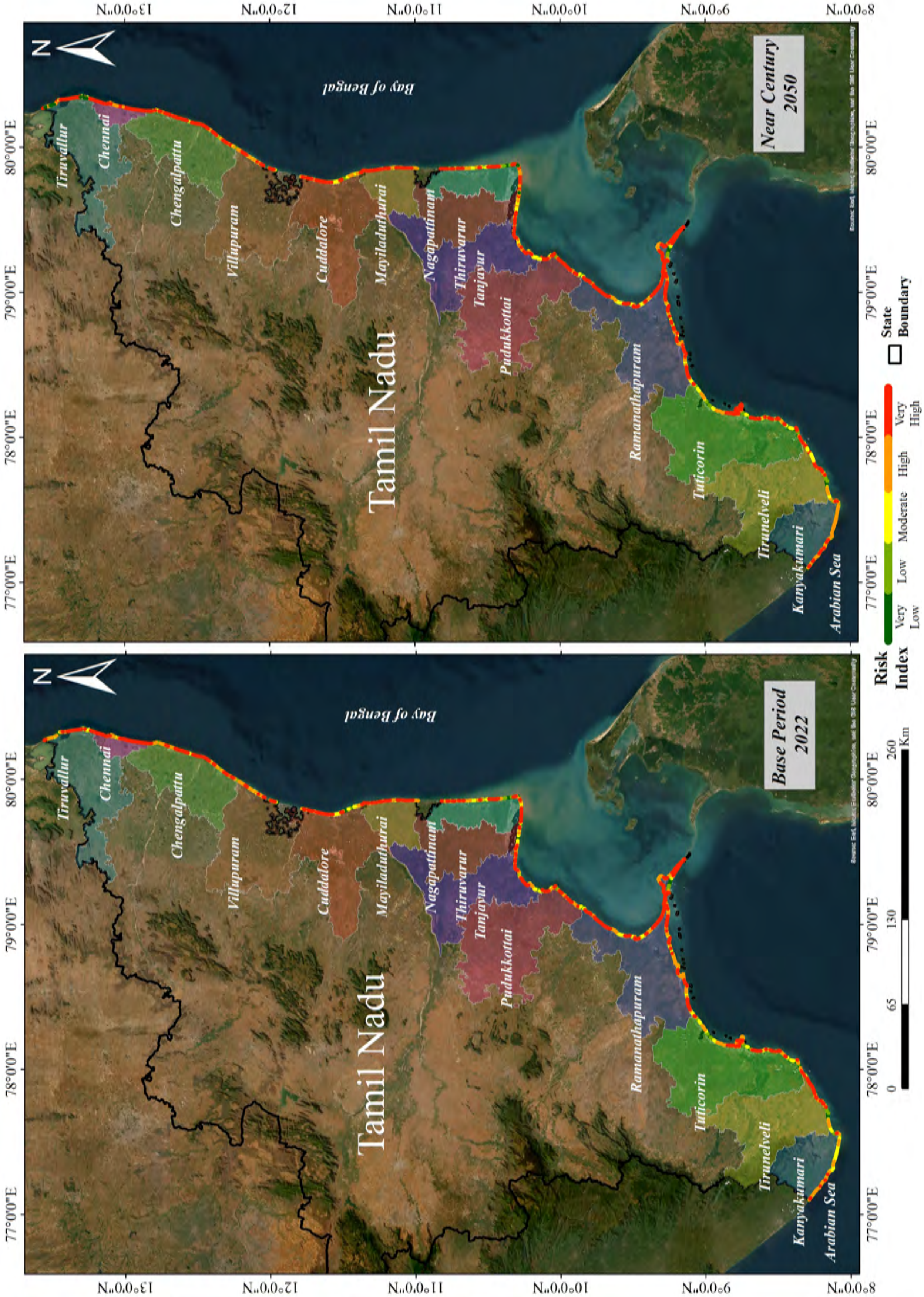


Figure 39 Coastal Risk Index map of Tamil Nadu

4. Coastal Vulnerability and Risk Assessment of coastal Districts

4.1 Tiruvallur

The district is situated between the coordinates of E longitudes 79° 17′34.8″ and 80° 2′34.8″ and N latitudes 13° 20′31.2″ and 12° 56′27.6″ has total geographical aerial extent of 1557.07 Sq. Km (Periyasamy et al., 2018) (Figure 40). The district has two blocks, Minjur and Puzhal Taluks, covering 34.5 km of coastal length. Ponneri and Gummmidipoondi are the coastal taluks more prone to cyclone disasters. The rivers flowing in the district include Kosasthalaiyaru, Araniyar, Nandi, Kallar, Coovam, and Buckingham. Tiruvallur district is one of the fastest developing districts in Tamil Nadu in terms of Industrial Development. It has a Kattupalli Port. Pulicat Lake is the second largest brackish water lake in India and is located between 13°26' and 13°43'N latitude and 80°03' and 80°18'E longitudes. Pulicat Lake is a very fragile ecosystem that provides nursery and breeding grounds for many species of marine fauna and supports commercial fishing with major fish landing centres at Pulicat and Arambakkam. According to the Tamil Nadu Fisheries Department in 2022, the district has a fisherman population of 19,996 individuals.

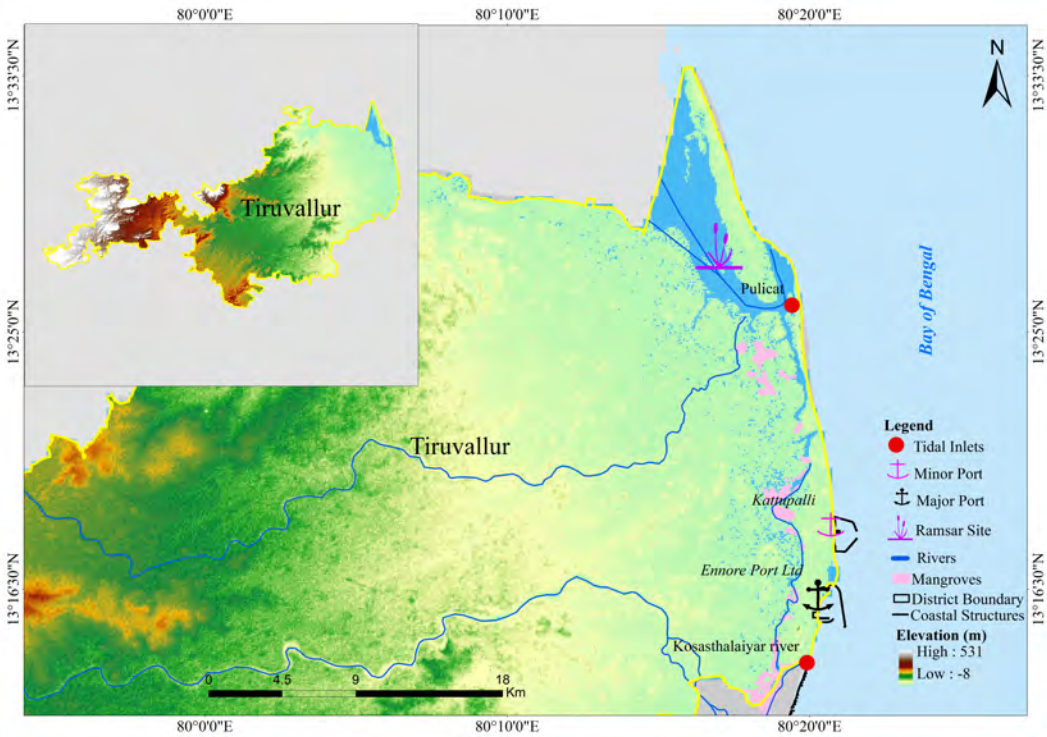


Figure 40 Coastal Profile map of Tiruvallur District

The coast of Tiruvallur District is characterized by a vast coastal plain that stretches from Toppala Palayam in the north to Sattangadu in the south. Along this coastal plain, there are three distinct strand lines separated by broad tidal flats. Within the coastal plains, various marine landforms can be found, including lagoons, mangrove swamps, salt marshes, estuaries, creeks, sand dunes, spits, and beach terraces. The coastline experiences both accretion and erosion, with erosion being particularly noticeable near Ennore. In addition, the development of offshore bars and shoals has been observed in the vicinity of Ennore and Pulicat (CRZ, 2000).

4.1.1 Land use Land Cover (LULC) of Tiruvallur District

The LULC assessment conducted for Tiruvallur District in 2022 revealed that the dominant land use is agriculture or crop land (61 %), followed by water bodies (12 %) and rural areas (7 %). Pulicat Lake and Kosasthalaiyar River are major waterbodies (Table 23). The district also covers approximately 360 hectares (0.1 %) of mangrove areas, particularly along the Kosasthalaiyar River (Figure 41).

Table 23. Land use Land Cover Assessment of Tiruvallur District.

S. No.	Land use Land Cover	Area(ha)	% of Total area
1	Built-up land (Urban)	13573	4
2	Built-up land (Rural)	22860	7
3	Vegetated/Open area	10427	3
4	Industrial/ Mining area	4275	1
5	Forest	9418	3
6	Lagoon, Creeks, Mud Flats, Swamp	7577	2
7	Saltpans	1277	0.4
8	Waterbody	40322	12
9	Sandy Beaches	744	0.2
10	Wastelands	16525	5
11	Agricultural land	196597	61
12	Mangroves	360	0.1
TOTAL		323955	100

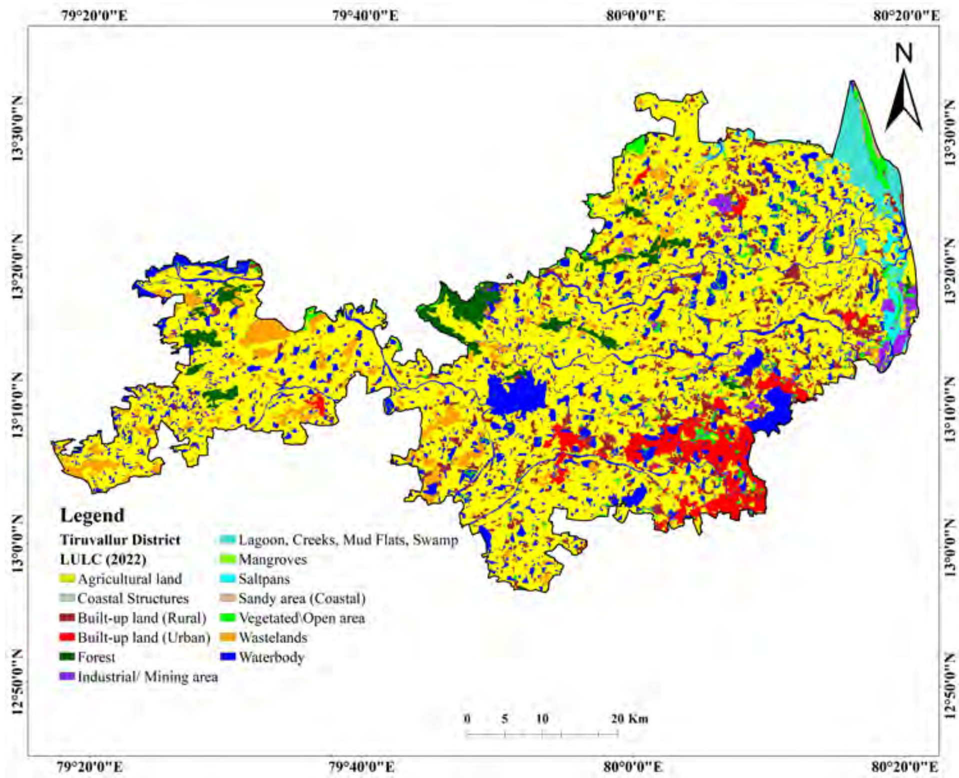


Figure 41 Land use and Land Cover (LULC) of Tiruvallur District

4.1.2 Assessment of the Shoreline Change for Tiruvallur District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), about 6.88 km of coastal length under high erosion, 2.16 km of coastline under moderate erosion, and 5.04 km under high accretion (Table 25). Out of 6.88 km of high erosion, 6.65 km of coast under Minjur block indicates the vulnerability of Minjur block to shoreline changes. The erosion rate is 3.7 m/year, while the accretion rate is 6.6 7 m/year. The eroding hotspot villages were identified, and the length was calculated. It is observed that Karimanallur, Kalanji, Kattupalli, and Karungali villages of Minjur block are highly eroded (Table 25), while Karimanallur, Ennore, and Athipattu villages are observed with high accretion (Table 26) (Figure 42). The study revealed that about 197 ha of land loss and 188 ha of land gain were observed in the Tiruvallur district area over a period of 30 years. The coastline is narrow, and both Pulicat Lake and Ennore Creek are covered with extensive mud flats. The coast is also dominated by man-made structures, i.e., thermal power plants, Ennore Port, and Kattupalli Port. These industrialization, urbanization, and development activities of port and fishing are playing significant roles in change in the shoreline. The studies also revealed the high erosion due to anthropogenic activities in this coastal region [Jayakumar and Malarvannan (2016); Jayakumar (2018); Subburaj et al., 2023; George et al., 2023)].

Table 24. Shoreline change assessment of Tiruvallur District.

S.No	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Minjur	31.48	6.65	2.16	7.76	7.48	3.44	0.49	3.50
2	Puzhal	3.04	0.23	-	0.50	0.30	0.30	0.18	1.54
	Total	34.52	6.88	2.16	8.26	7.78	3.74	0.67	5.04

HE - High Erosion,ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

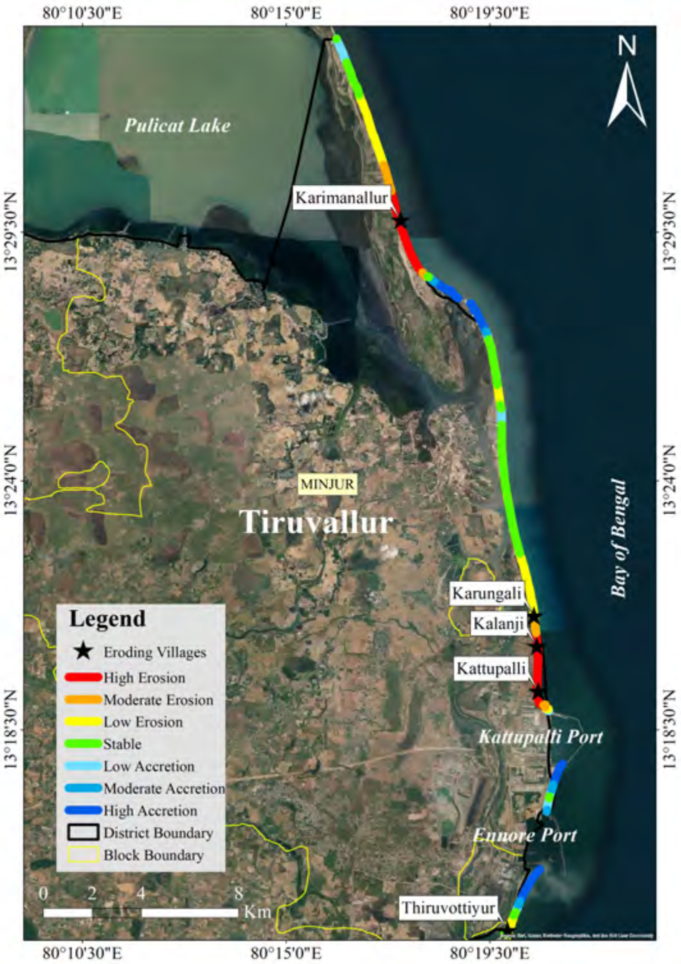


Figure 42 Shoreline Change map of Tiruvallur District from 1992 - 2022

Table 25. Eroding hotspots of Tiruvallur District.

S.No	District Name	Block Name	Village Name	Length in Km
1	Tiruvallur	Minjur	Karimanallur	4.99
2			Karungali	0.3
3			Kalanji	2.17
4			Kattupalli	1.54

Table 26. Accretion dominant villages in Tiruvallur District.

S.No	District Name	Block Name	Village Name	Length in Km
1	Tiruvallur	Minjur	Karimanallur	3.25
2			Athipattu	1.14
3		Puzhal	Ennore	2.43

4.1.3 SLR Projections and Coastal Inundation in Tiruvallur District

The projection of the total trend of SLR for the Tiruvallur coast based on the SSP2 4.5 scenario (Medium Projection) for the near century is estimated as an average of 19.2 cm (Figure 43). The coastal inundation due to the rise in sea level is projected to be about 4000 ha. The inundation effect is mostly on Lagoon, Creeks, Mudflats, and also on Waterbodies and Sandy areas (Figure 44).

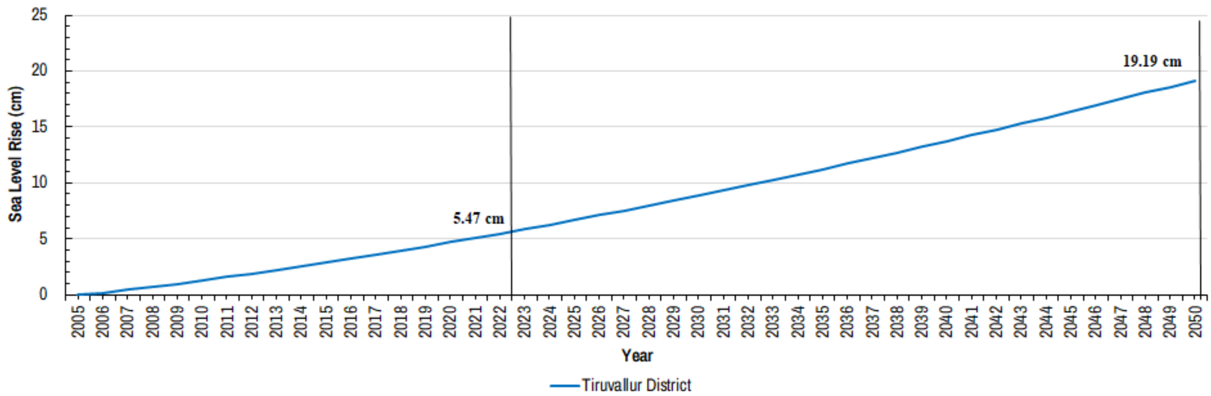


Figure 43 Projected SLR of Tiruvallur District under SSP2- 4.5 (cm) for the Near Century

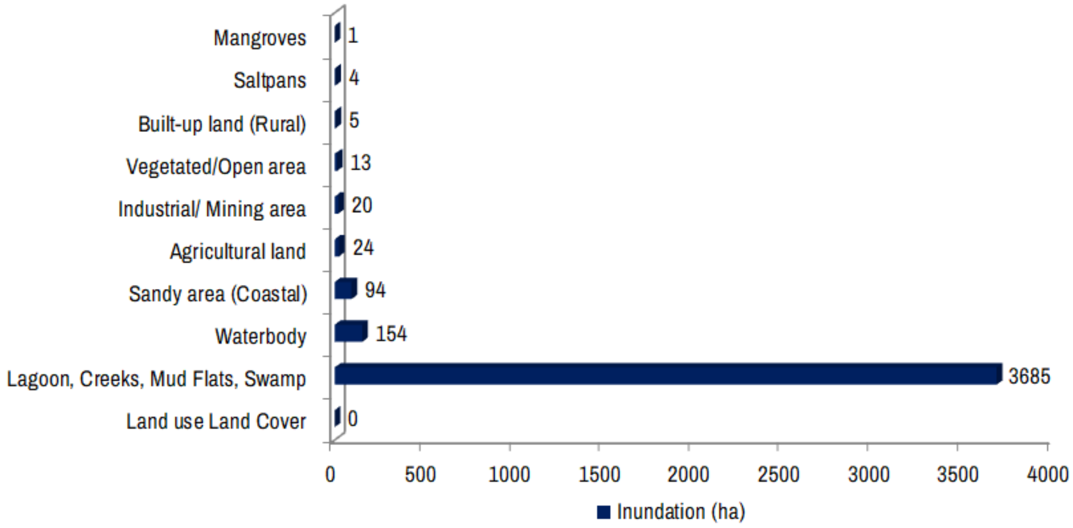


Figure 44 Impact of coastal inundation on land use land cover of Tiruvallur District.

4.1.4 Coastal Risk Assessment of Tiruvallur District

The coastline of Tiruvallur is highly prone to multiple hazards, with 24 km in the baseperiod and 28 km in the projected period being particularly susceptible (Table 27). In terms of vulnerability and exposure, the Tiruvallur coast is classified as high - very high (Figure 45). Consequently, the risk for the coastline has increased both in the baseline and projected periods.

Table 27. Integrated Coastal Risk Assessment for Tiruvallur District (km).

S. No	Tiruvallur	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	0.7	0.5	0.1	0.0	1.9	1.6
2	Low	1.7	1.4	2.2	9.5	7.5	5.5
3	Moderate	16.4	13.3	2.3	11.5	9.2	9.2
4	High – Very High	24.3	27.9	38.5	22.2	24.5	26.9
	Total	43.2	43.2	43.2	43.2	43.2	43.2

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

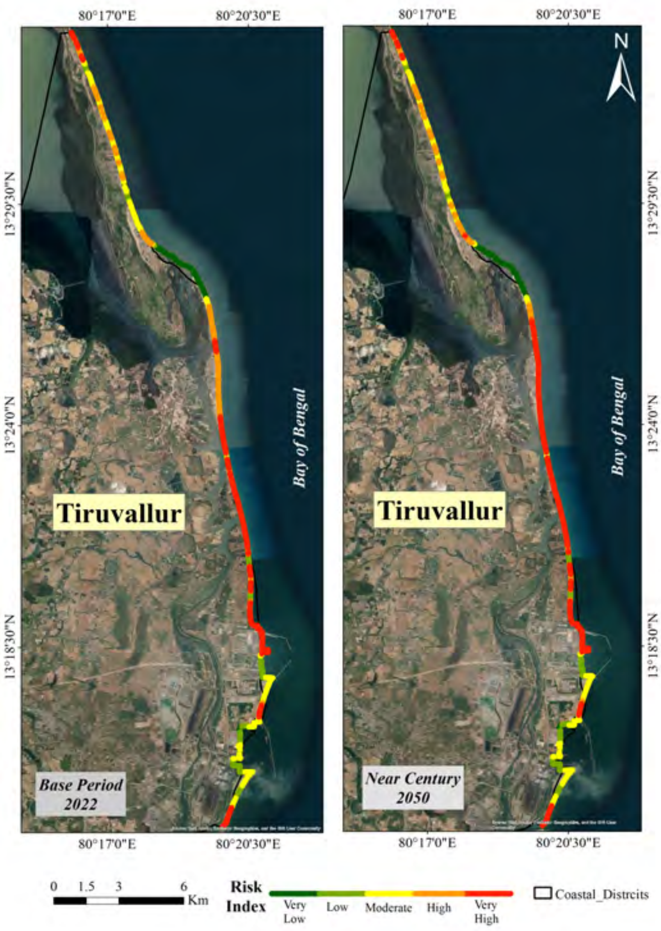


Figure 45 Coastal Risk Index map of Tiruvallur District

4.2 Chennai

Chennai is called as the "Gateway to South India" and extends between 13°4′57″N Latitude and 80°16′30″E Longitude (Figure 46). The district is part of the Coromandel Coast; it has three blocks such as Puzhal, Chennai District and ST. Thomas Mount Taluks cover 19 km of coastal length. The city is prone to flooding during the Northeast monsoon and has experienced significant damage in past flood events. The 2004 Indian Ocean tsunami also caused severe damage. The rivers flowing in the district include Kortalaiyar, Cooum, and Adyar. It has two major ports: Chennai Port, the largest artificial port in India, and Ennore Port. The Royapuram fishing harbour is used by fishing boats and trawlers. Marina Beach is the world's second-longest beach, formed of a sandy coast extending 12 km from Fort St. George in the north to Besant Nagar in the south. According to the Tamil Nadu Fisheries Department in 2022, the district has a fisherman population of 27,668 individuals.

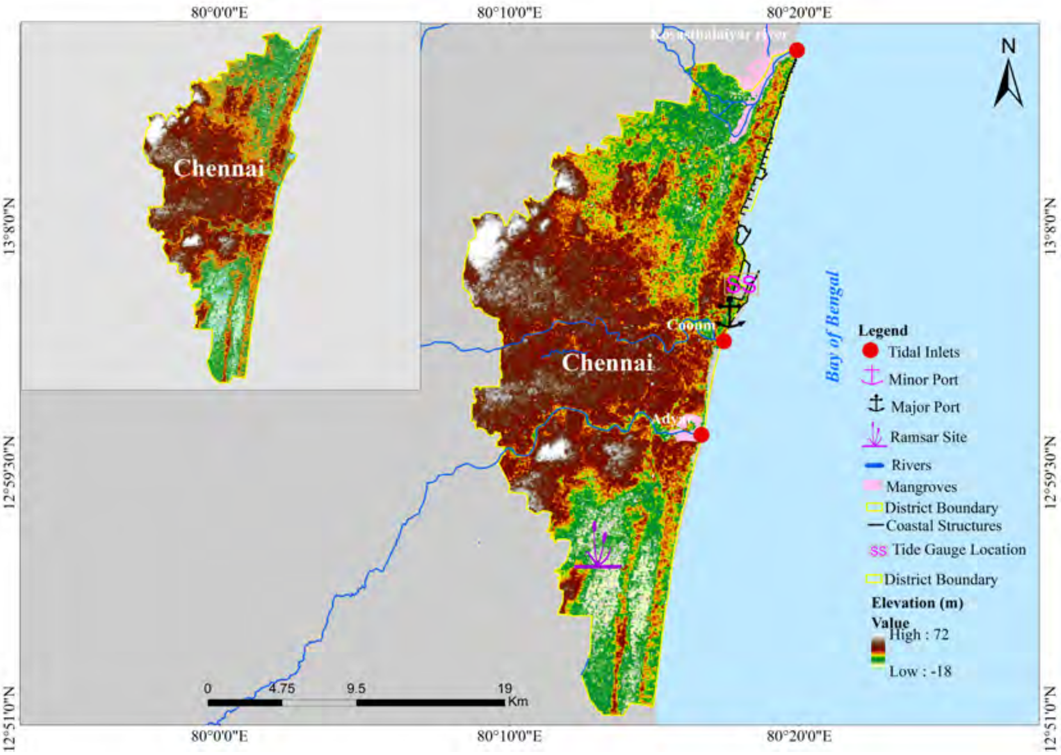


Figure 46 Coastal Profile map of Chennai District

The majority of the district has a flat topography with a gentle slope towards the east. The altitude of the land varies from 10 meters above MSL. Different types of landforms, including fluvial, marine, and erosional formations, can be observed throughout the district (CGWB, 2008). The district have experienced significant disturbance due to urban development, with large-scale human interference and pollution.

4.2.1 Land use Land Cover (LULC) of Chennai District

The LULC assessment conducted for Chennai District in 2022 revealed that the dominant land use is Urban land (64.6 %), followed by Vegetated/Open area (12 %) and Industrial/Mining area (7 %) (Table 28). The district also covers approximately 174 hectares (0.1 %) of mangrove areas, particularly along the Adayar River (Figure 47).

Table 28. Land use Land Cover Assessment of Chennai District.

S. No.	Land use Land Cover	Area (ha)	% of Total Area
1	Built-up land (Urban)	28330	64.6
2	Built-up land (Rural)	721	1.6
3	Vegetated/Open area	4112	9.4
4	Industrial/Mining area	3673	8.4
5	Forest	368	0.8
6	Lagoons, Creeks, Mud Flats, Swamp	1293	2.9
7	Saltpans	15	0.0
8	Waterbody	2641	6.0
9	Sandy Beaches	313	0.7
10	Wastelands	628	1.4
11	Agricultural land	1566	3.6
12	Mangroves	174	0.4
Total		43868	100.0

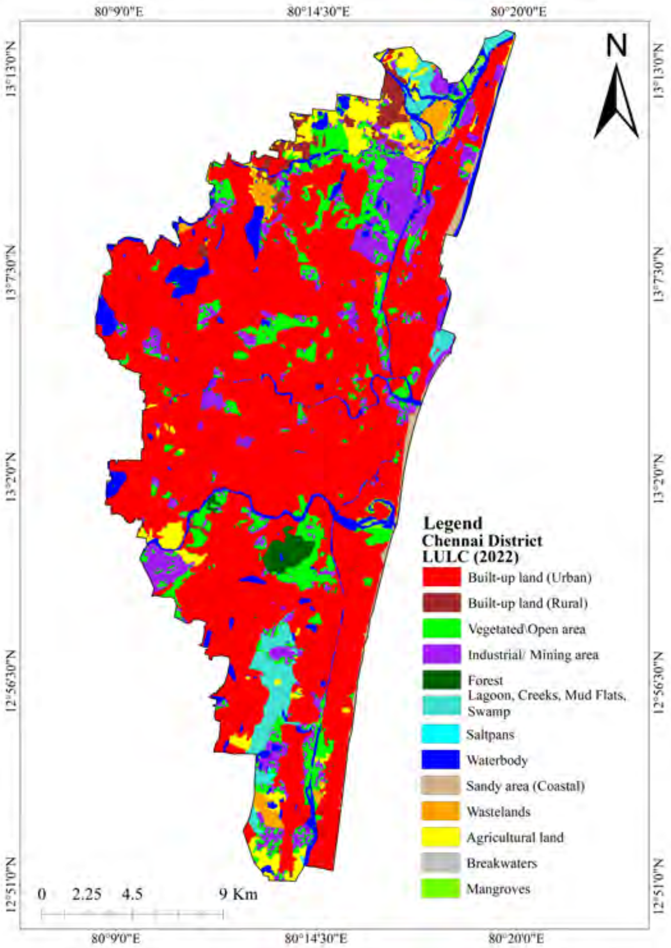


Figure 47 Land use and Land Cover (LULC) of Chennai District

4.2.2 Assessment of the Shoreline Change for Chennai District (1992-2022)

The assessment of shoreline changes for the Chennai coast revealed that most of the coastline is stable (19.46). About 9.7 km is under low erosion, and 2.12 km is under moderate erosion (Table 29). Accretion was observed in 7.7 km of coastline. Thiruvottiyur of Puzhal is identified as an eroding hotspot (Table 30), which is around 7.6 km eroding (Figure 48). The erosion accretion rate of the Chennai coast showed 1.3 m/year and 0.9 m/year respectively. The land loss and land gain assessments revealed 58 ha and 55 ha, respectively. Overall, between the years 1992-2022, the Chennai coast is mostly stable along the southern part of Chennai Port. Areas like Marina Beach, Nocchi Kuppam, Dumming Kuppam, Elliot's Beach and Kaveri Nagar are stable, whereas the North of the port is a mixture of Accretion and Erosion. The previous studies also showed similar results (Shanmugam and Nayak, 2013; Khan and Thanappan, 2020).

Table 29. Shoreline change assessment of Chennai District.

S.No	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Puzhal	10.62	-	2.12	7.07	1.08	0.34	-	-
2	Chennai_Dist	15.68	-	-	0.47	7.46	7.26	0.41	0.09
3	ST.Thomas_MT	13.21	-	-	2.17	10.92	0.12	-	-
	Total	39.51	-	2.12	9.71	19.46	7.72	0.41	0.09

HE - High Erosion, ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

Table 30. Eroding hotspots of Chennai District.

S.No	District Name	Block Name	Firka Name	Length in Km
1	Chennai	Puzhal	Thiruvottiyur	7.59

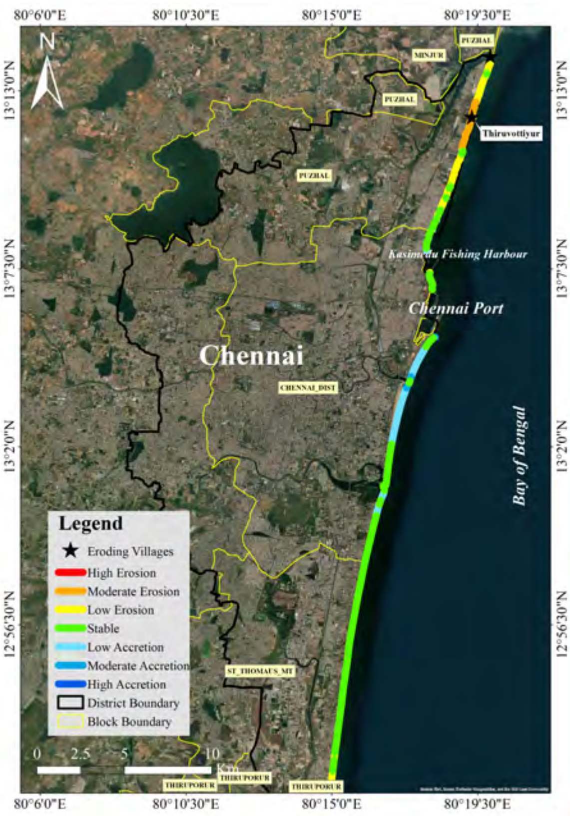


Figure 48 Shoreline Change map of Chennai District from 1992 - 2022

4.2.3 SLR Projections and Coastal Inundation in Chennai District

The projection of the total trend of SLR for the Chennai coast based on the SSP2 4.5 scenario (Medium Projection) for the near century is estimated to have an average of 19.2 cm (Figure 49). The coastal inundation due to the rise in sea level is projected to be about 471 ha. The Sandy areas and Lagoon, Creeks, Mud Flats, and Swamp are at high risk due to inundation (Figure 50).

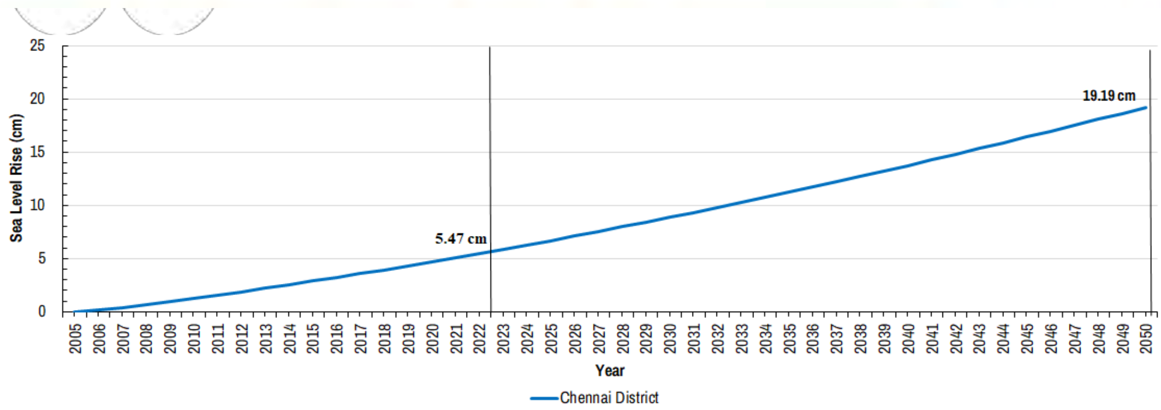


Figure 49 Projected SLR of Chennai District under SSP2- 4.5 (cm) for the Near Century

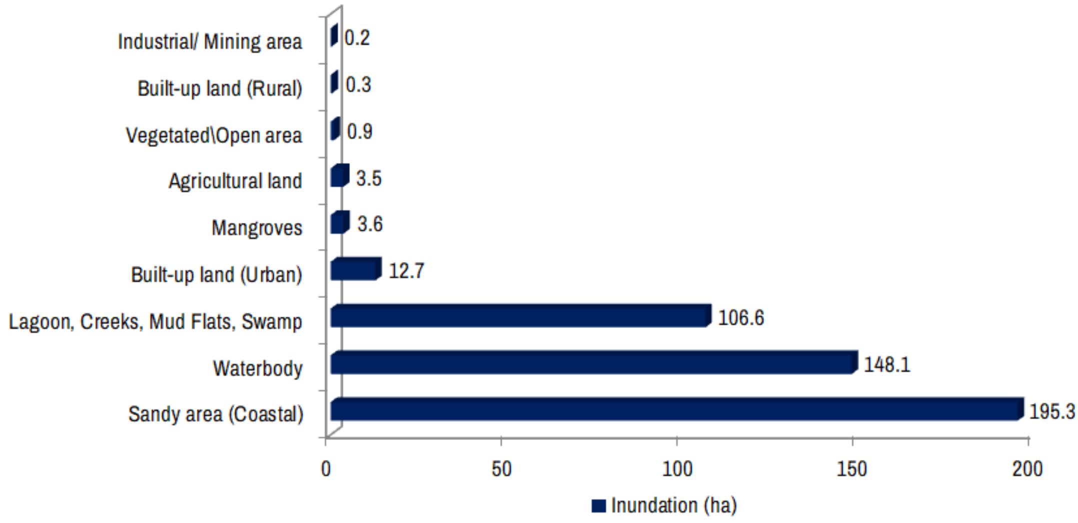


Figure 50 Impact of coastal inundation on land use land cover of Chennai District.

4.2.4 Coastal Risk Assessment of Chennai District

The coastline of Chennai is highly prone to multiple hazards, with 38 km in the base period and 39 km in the projected period being particularly susceptible. In terms of vulnerability and exposure, the Chennai coast is classified as very high (Table 31). Consequently, the risk for the coastline has increased both in the baseline and projected periods from 28.2 km to 30.7 km (Figure 51).

Table 31. Integrated Coastal Risk Assessment for Chennai District (km).

S. No	Chennai	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	0.0	0.0	0.4	0.2	4.7	3.8
2	Low	5.3	4.7	1.5	1.2	6.7	5.1
3	Moderate	5.2	4.8	2.3	10.2	8.8	8.8
4	High – Very High	38.0	39.0	44.2	36.8	28.2	30.7
	Total	48.4	48.4	48.4	48.4	48.4	48.4

HE - High Erosion, ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

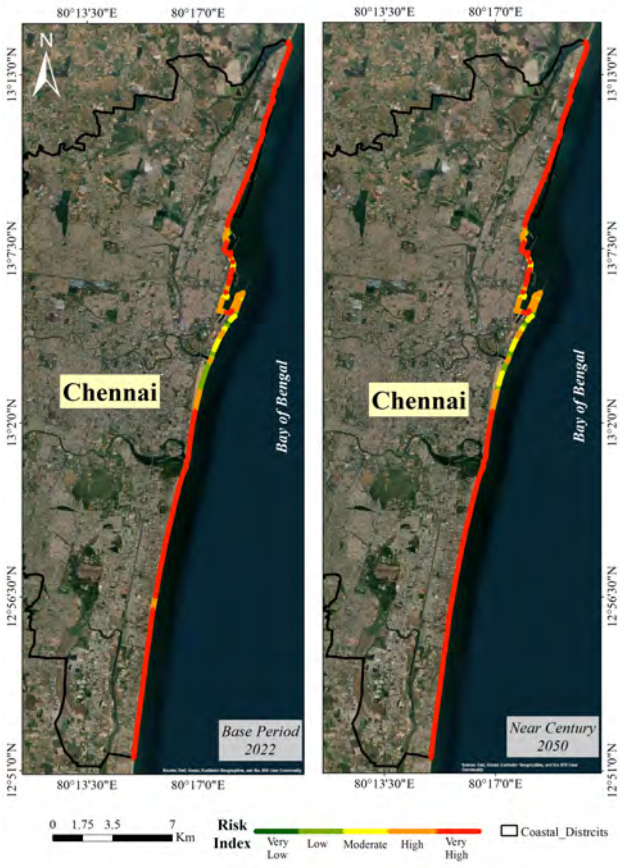


Figure 51 Coastal Risk Index map of Chennai District

4.3 Chengalpattu

Chengalpattu is part of the Coromandel Coast extends between 12°40′54.8″N Latitude and 79°59′19.7″E Longitude (Figure 52). The district is part of the Coromandel coast, and it has four blocks, Thiruporur, Thirukalukundrum, Lathur, and Chitamur, covering 87.2 km of coastal length. The district is highly prone to cyclones, and so far, 8 severe cyclonic storms hit the district. The rivers flowing in the district, such as Adyar in the north, Palar and Ongur in the south and Neenjal Maduvu, Pukkadurai Odai, and Kiliyar, are other minor rivers flowing through Chengalpattu district. Extensive salt manufacturing also took place along the coast. Mahabalipuram is an important world heritage and coastal tourist spot, having exotic and long sea shore temples in the form of Chariots called Rathas and Mandapams. According to the Tamil Nadu Fisheries Department in 2022, the district has a fisherman population of 12,237 individuals.

Geomorphology of the Chengapattu District consist of young coastal plain (beach, ridges, mudflats and brackishwater creeks), alluvial younger plain, flood plain, deep coastal plain, deep alluvial plain, moderately buried pediplain, older coastal plain and older alluvial plain (ICAR-CIBA, 2022).

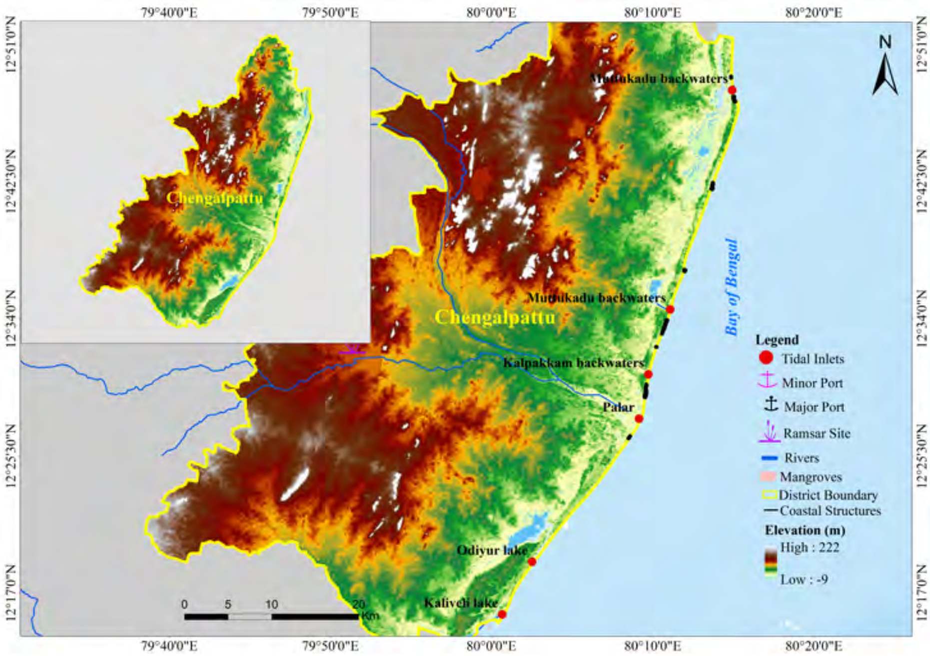


Figure 52 Coastal Profile map of Chengalpattu District.

4.3.1 Land use Land Cover (LULC) of Chengalpattu District

The LULC assessment conducted for Chengalpattu District in 2022 revealed that the dominant land use is agriculture or crop land (57 %), followed by water bodies (13 %) and rural areas (8 %) (Table 32). The district also covers approximately 11 hectares (0.1 %) of mangrove areas (Figure 53).

Table 32. Land use Land Cover Assessment of Chengalpattu District.

S. No.	Land use Land Cover	Area (ha)	% of Total area
1	Built-up land (Urban)	15344	5.8
2	Built-up land (Rural)	20463	7.7
3	Vegetated/Open area	6743	2.5
4	Industrial/ Mining area	2337	0.9
5	Forest	12088	4.6
6	Lagoon, Creeks, Mud Flats, Swamp	4050	1.5
7	Saltpans	2151	0.8
8	Waterbody	35211	13.3
9	Sandy Beaches	1048	0.4
10	Wastelands	13378	5.0
11	Agricultural land	152226	57.4
12	Mangroves	11	0.004
TOTAL		265059	100.0

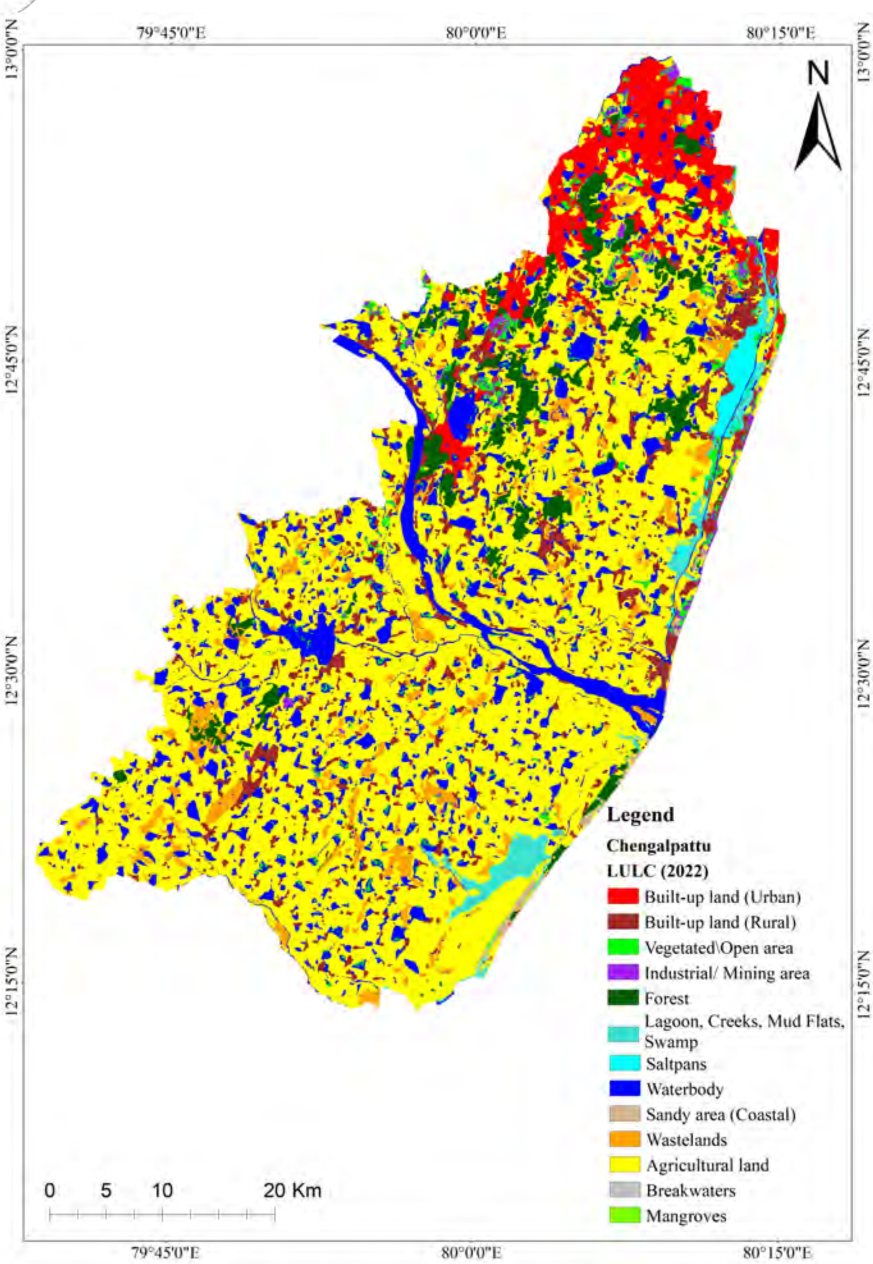


Figure 53 Land use and Land Cover (LULC) of Chengalpattu District

4.3.2 Assessment of the Shoreline Change for Chengalpattu District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), about 1.64 km of coastal length under moderate erosion, while 1.02 km under moderate accretion (Table 33). Out of 74.58 km of coastal length, low erosion was shown in 42.21 km of coastline, while 9.69 km of low accretion was observed. Kadaloor village of Lathur is identified as an eroding hotspot with a 3.44 km eroding coast (Table 34), and Muttukadu village Thiruporur block dominant with accretion (Table 35) (Figure 54). The erosion rate observed is 0.9 m/year, while the accretion rate is 1 m/year. The study revealed that about 156 ha of land loss and 45 ha of land gain were observed in the Chengalpattu district area over a period of 30 years.

Table 33. Shoreline change assessment of Chengalpattu District.

S.No	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Thiruporur	23.67	-	-	10.63	9.27	2.99	0.79	-
2	Thirukalukundrum	20.24	-	-	8.08	5.78	6.15	0.23	-
3	Lathur	19.55	-	1.64	16.96	0.94	-	-	-
4	Chitamur	11.12	-	-	6.54	4.03	0.55	-	-
	Total	74.58	-	1.64	42.21	20.02	9.69	1.02	-

HE - High Erosion,ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

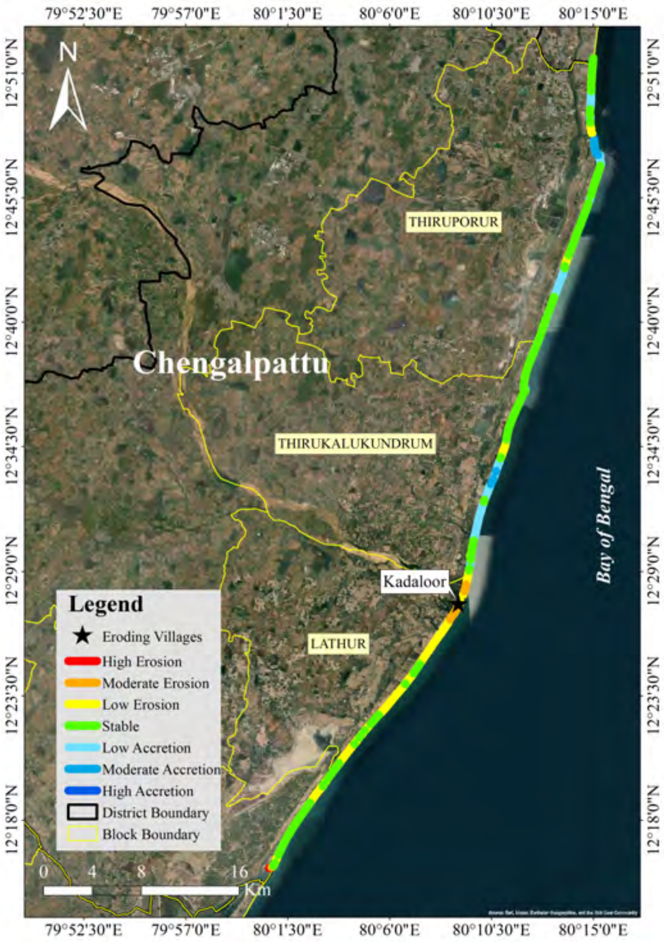


Figure 54 Shoreline Change map of Chengalpattu District from 1992 - 2022

Table 34. Eroding hotspots of Chengalpattu District.

S.No	District Name	Block Name	Village Name	Length in Km
1	Chengalpattu	Lathur	Kadaloor	3.44

Table 35. Accretion dominant villages in Chengalpattu District.

S.No	District Name	Block Name	Village Name	Length in Km
1	Chengalpattu	Thiruporur	Muttukadu	1.25

4.3.3 SLR Projections and Coastal Inundation in Chengalpattu District

The projection of the total trend of SLR for the Chengalpattu coast based on the SSP2 4.5 scenario for the near century is estimated as an average of 19.3 cm (Medium Projection) (Figure 55). The coastal inundation due to the rise in sea level is projected to be about 1634 ha. The Lagoon, Creeks, Mudflats, Swamp, Agricultural land, and Waterbody Sandy Beaches are at high risk due to inundation) (Figure 56).

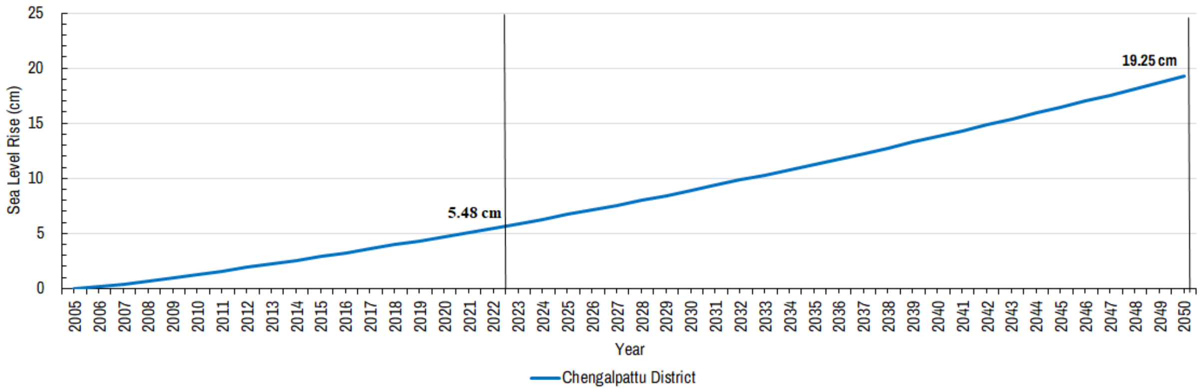


Figure 55 Projected SLR of Chengalpattu District under SSP2- 4.5 (cm) for the Near Century

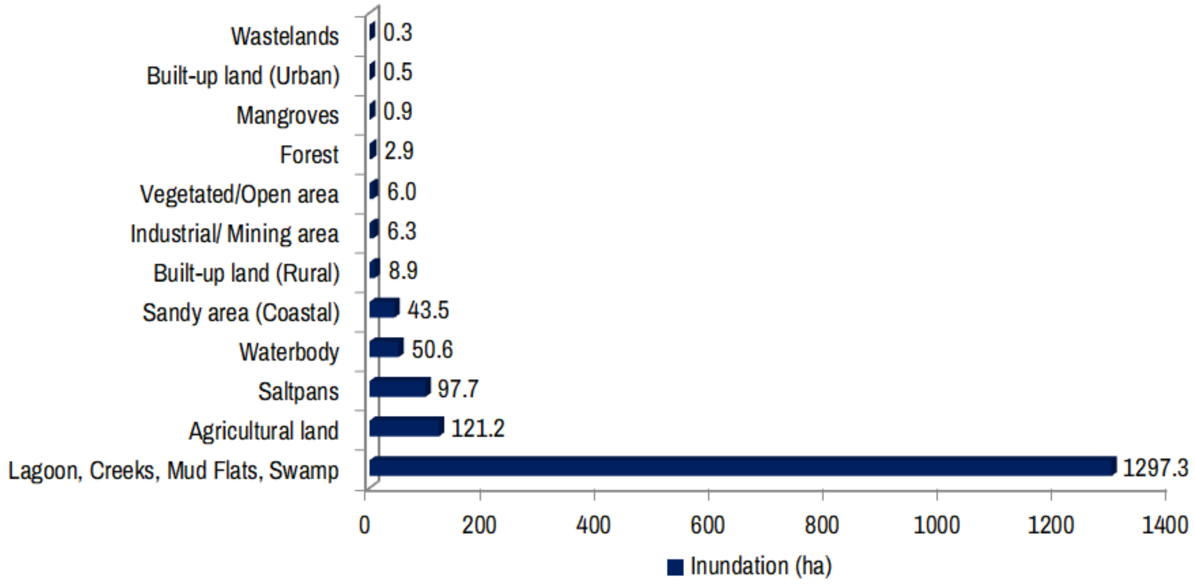


Figure 56 Impact of coastal inundation on land use land cover of Chengalpattu District.

4.3.4 Coastal Risk Assessment of Chengalpattu District

The coastline of Chengalpattu is extremely susceptible to various hazards, and about 66.6 km of stretch that is particularly susceptible. The vulnerability assessment classifies the Chengalpattu coast as having both high - very high vulnerability levels. Specifically, 73.5 km of the coastline is classified as high - very high vulnerability (Figure 57). As a result of this heightened vulnerability, the risk for the entire Chengalpattu coastline has increased during both the baseline and projected periods. The baseline period estimated a total risk extent of 36.8 km (Table 36). However, in the projected periods, the risk extent has risen to 44.6 km, indicating an increase in the coastline exposed to potential hazards and damage.

Table 36. Integrated Coastal Risk Assessment for Chengalpattu District (km).

S. No	Chengalpattu	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	0.0	0.0	0.1	13.5	12.6	9.2
2	Low	0.5	0.4	0.0	22.6	12.5	10.3
3	Moderate	7.5	6.9	1.1	20.5	12.7	10.5
4	High – Very High	66.6	67.3	73.5	18.0	36.8	44.6
	Total	74.6	74.6	74.6	74.6	74.6	74.6

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

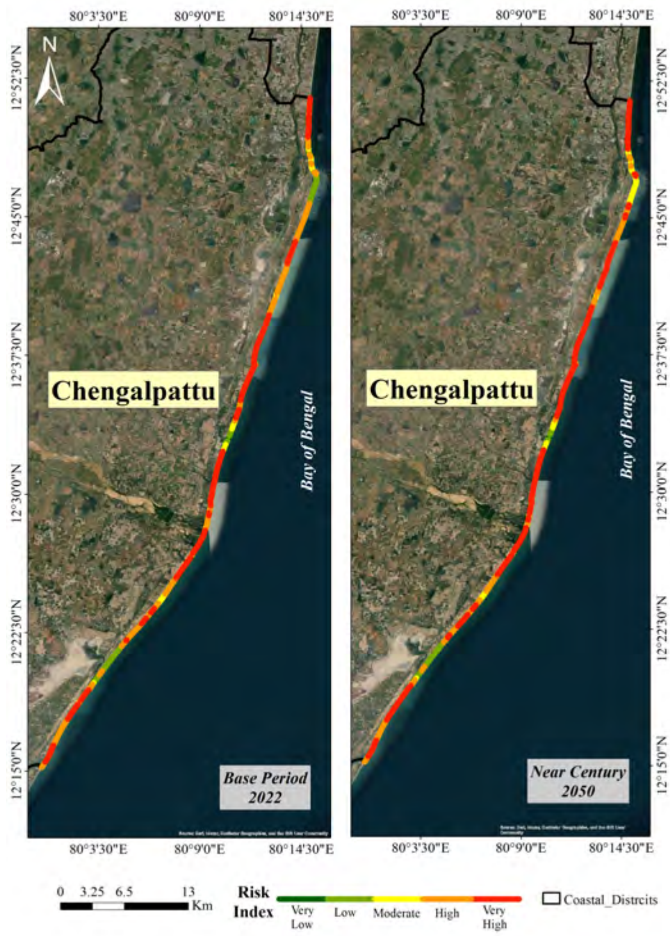


Figure 57 Coastal Risk Index map of Chengalpattu District

4.4. Villupuram

Villupuram is part of the Coromandel coast and extends between 11°56'24.5"N Latitude 79°29'10.1"E Longitude (Figure 58). The district has two blocks, Marakkanam and Vanur Taluks, which cover 40.7 km of coastal length. The district is highly prone to cyclones, and so far, 4 severe cyclonic storms have hit the district. It has 19 fish landing places. Villupuram stands in second position in Tamil Nadu in the projduction of salt at Marakkanam. According to the Tamil Nadu Fisheries Department in 2022, the district has a fisherman population of 6222 individuals.

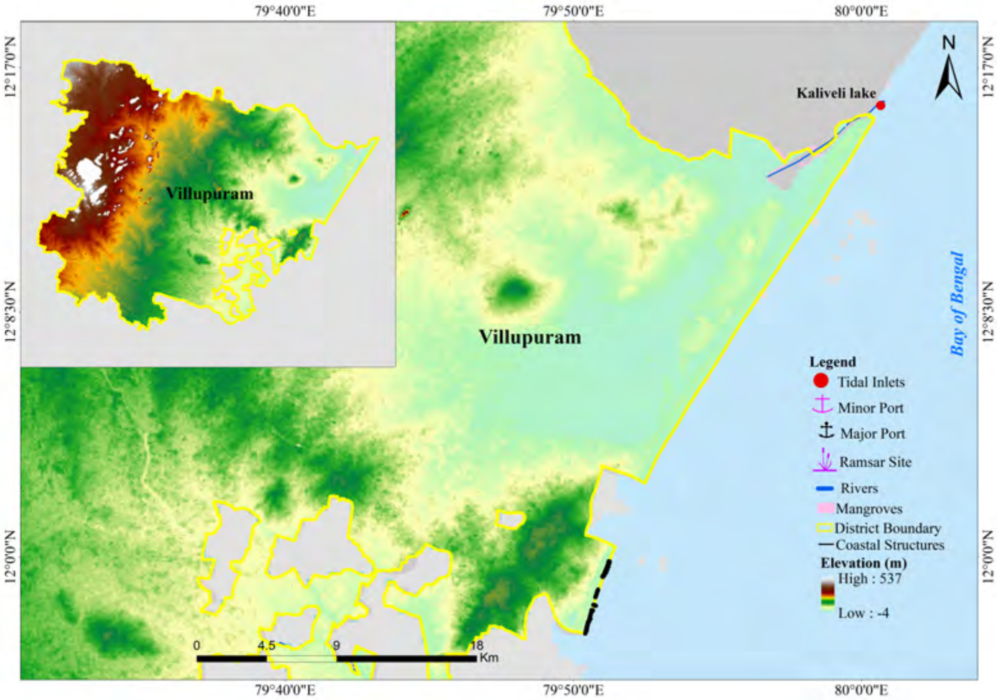


Figure 58 Coastal Profile map of Villupuram District

The northern part of the coast has sandy beach. The extreme south part of this coast is covered by swamps and mangrove forest. The ground slope is gentle towards the coast. The valley fill near Villupuram is thick, which forms the main ground water discharge zone (DHDR-SPC, 2017).

4.4.1 Land use Land Cover (LULC) of Villupuram District

The LULC assessment conducted for Villupuram District in 2022 revealed that the dominant land use is agriculture or crop land (77.6 %), followed by water bodies (10.6 %) and Forest (7 %) (Table 37). The district also covers approximately 141 hectares (0.1 %) of mangrove areas (Figure 59).

Table 37. Land use Land Cover Assessment of Villupuram District.

S. No.	Land use Land Cover	Area (ha)	% of Total area
1	Built-up land (Urban)	2214	0.6
2	Built-up land (Rural)	11019	2.8
3	Vegetated/Open area	7546	1.9
4	Industrial/ Mining area	1216	0.3
5	Forest	13578	3.5
6	Lagoon, Creeks, Mud Flats, Swamp	355	0.1
7	Saltpans	614	0.2
8	Waterbody	41595	10.6
9	Sandy Beaches	1020	0.3
10	Wastelands	8512	2.2

11	Agricultural land	304909	77.6
12	Mangroves	141	0.0
TOTAL		392725	100.0

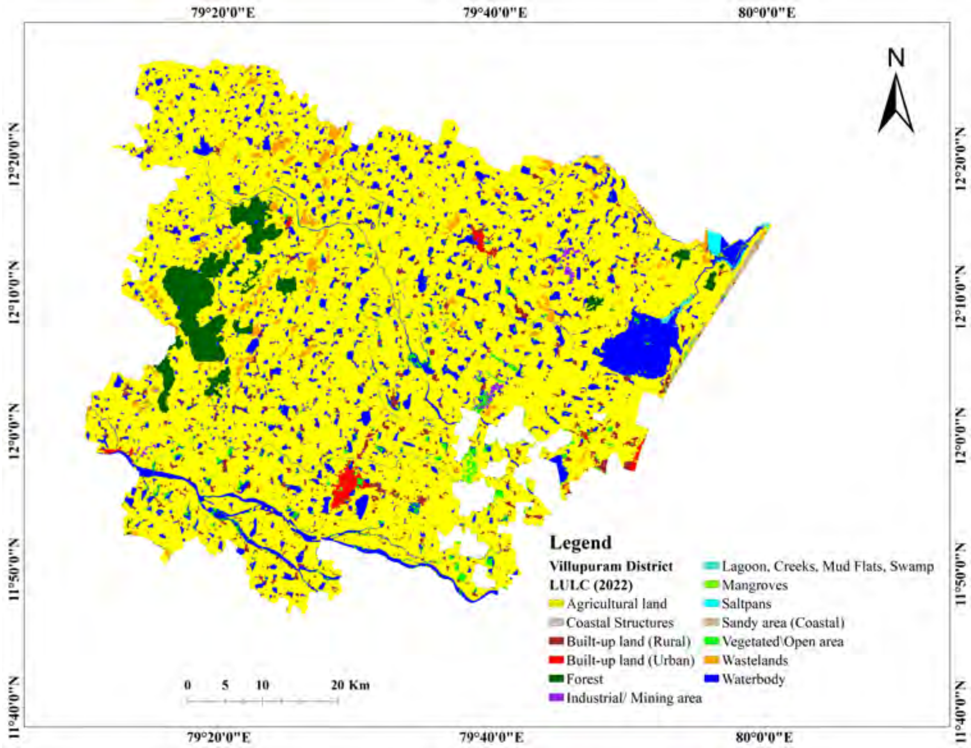


Figure 59 Land use and Land Cover (LULC) of Villupuram District

4.4.2 Assessment of the Shoreline Change for Villupuram District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), approximately 12.87 km of coastal length experienced low erosion (Table 38). About 4.79 km of coastal length underwent low accretion. Kottakuppam and Bommaiyarpalayam villages in Vanur were identified as eroding hotspots (Table 39), with 1.54 km and 0.21 km of eroding coast, respectively (Figure 60). The erosion rate was observed to be 0.9 m/year, while the accretion rate was 1 m/year . Over a period of 30 years, the study found 80 ha of land loss and 1 ha of land gain in the Villupuram district area. These findings provide insights into the coastal changes and their impact on land in the Villupuram district.

Table 38. Shoreline change assessment of Villupuram District.

S.No	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Marakkanam	27.47	-	-	8.29	14.67	4.52	-	-
2	Vanur	6.22	-	0.46	4.59	0.90	0.27	-	-
	Total	33.69	-	0.46	12.87	15.56	4.79	-	-

HE - High Erosion,ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

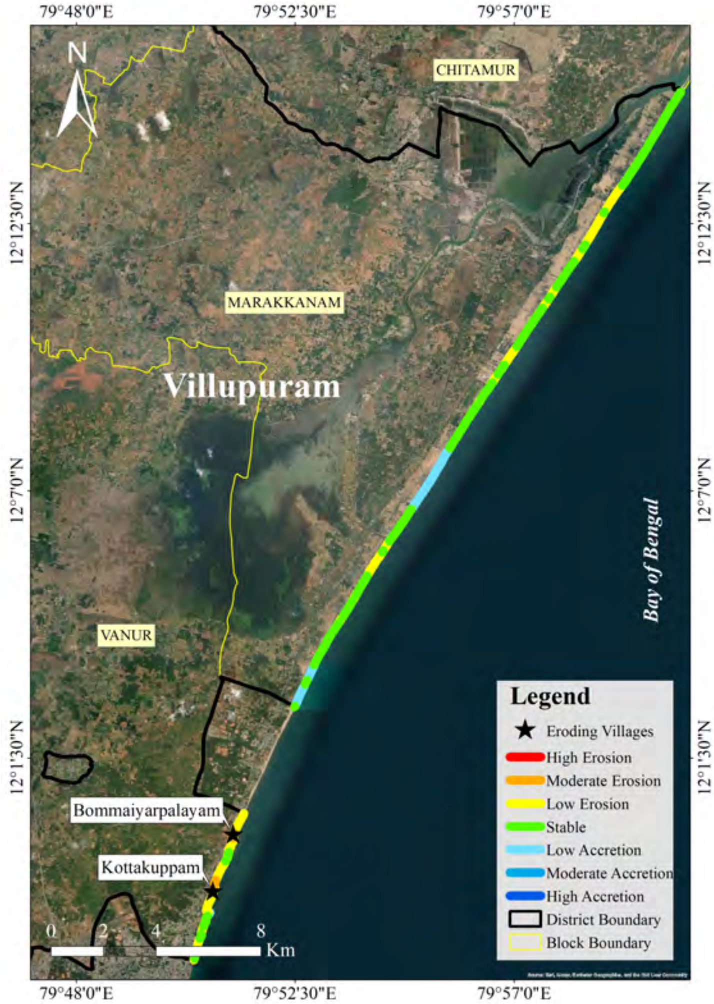


Figure 60 Shoreline Change map of Viluppuram District from 1992 - 2022

Table 39. Eroding hotspots of Villupuram District.

S.No	District Name	Block Name	Village Name	Length in Km
1	Vilupuram	Vanur	Bommaiyarpalayam	0.21
2			Kottakuppam	1.54

4.4.3 SLR Projections and Coastal Inundation in Villupuram District

The projection of the total trend of SLR for the Villupuram coast based on the SSP2 4.5 scenario (Medium Projection) for the near century is estimated as an average of 19.3 cm (Figure 61). The coastal inundation due to the rise in sea level is projected to be about 430 ha. The Lagoon, Creeks, Mudflats, Swamp, Agricultural land, and Waterbody Sandy Beaches are at high risk due to inundation (Figure 62).

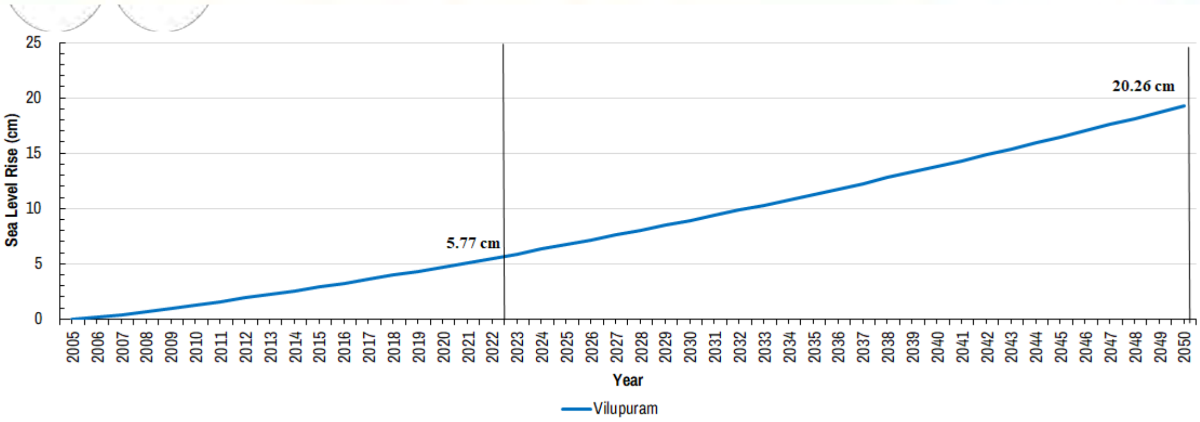


Figure 61 Projected SLR of Viluppuram District under SSP2- 4.5 (cm) for the Near Century

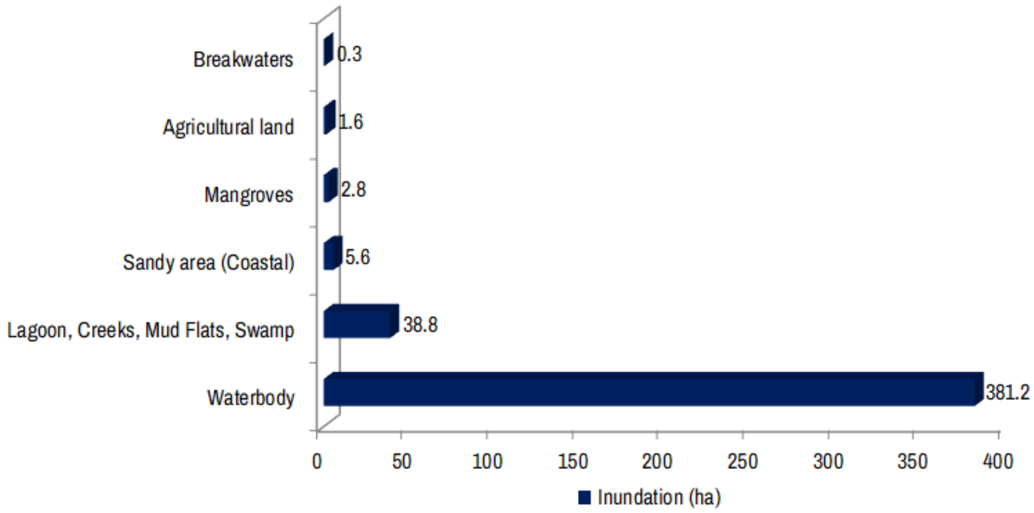


Figure 62 Impact of coastal inundation on land use land cover of Villupuram District.

4.1.4 Coastal Risk Assessment of Viluppuram District

The coastline of Villupuram is highly vulnerable to multiple hazards, with 15.5km in the baseperiod and 18.7 km in the projected period being particularly susceptible (Figure 63). In terms of vulnerability and exposure, the Villupuram coast is classified as very high. Thus, the risk for the coastline has increased both in the baseline and projected periods from 15 km to 19.1 km (Table 40).

Table 40. Integrated Coastal Risk Assessment for Villupuram District (km).

S.No	Villupuram	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	0.0	0.0	1.8	4.9	3.5	2.8
2	Low	11.6	9.7	2.4	8.2	8.8	5.1
3	Moderate	6.6	5.3	4.9	8.4	6.4	6.7

4	High – Very High	15.5	18.7	24.5	12.1	15.0	19.1
	Total	33.7	33.7	33.7	33.7	33.7	33.7

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

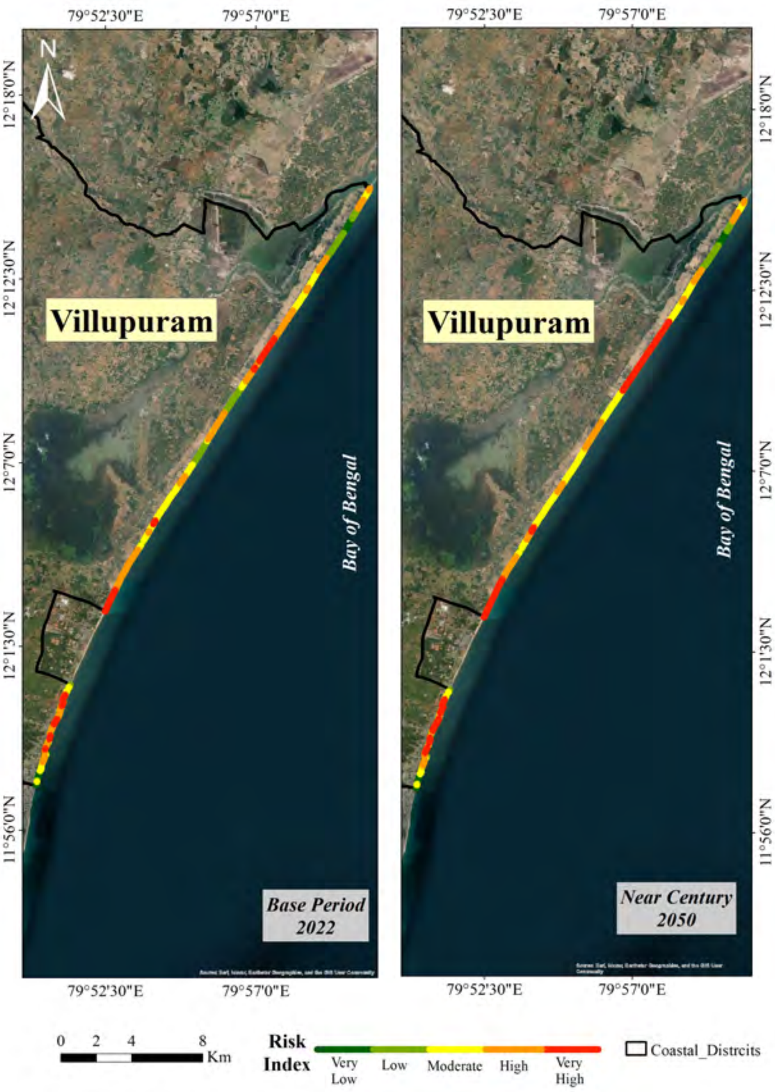


Figure 63 Coastal Risk Index map of Viluppuram District

4.5 Cuddalore

Cuddalore extends between 15^0 5” to 12^0 35” N latitude and between 78^0 38” to 80^0 00” E longitude (Figure 64). The rivers flowing in the district are Thenpennaiyar, Kedilam, Vellar, and Manimuthar. The district is part of the Coromandel coast and has three blocks, Cuddalore, Kurinchipadi, and Parangipettai, covering 57.5 km of coastal length. The district is highly prone to cyclones, and so far, 6 severe cyclonic storms hit the district. It was worse affected by the Indian Ocean tsunami in 2004.

Pichavaram is the second largest Mangrove forest in the world and is located between 11°20' to 11°30'N latitude and 79°45' to 79°55'E longitudes. It is situated between the vellar-pichavaram-coleroon estuaries. It acts as the breeding and nursery grounds to sequester carbon in the soil.

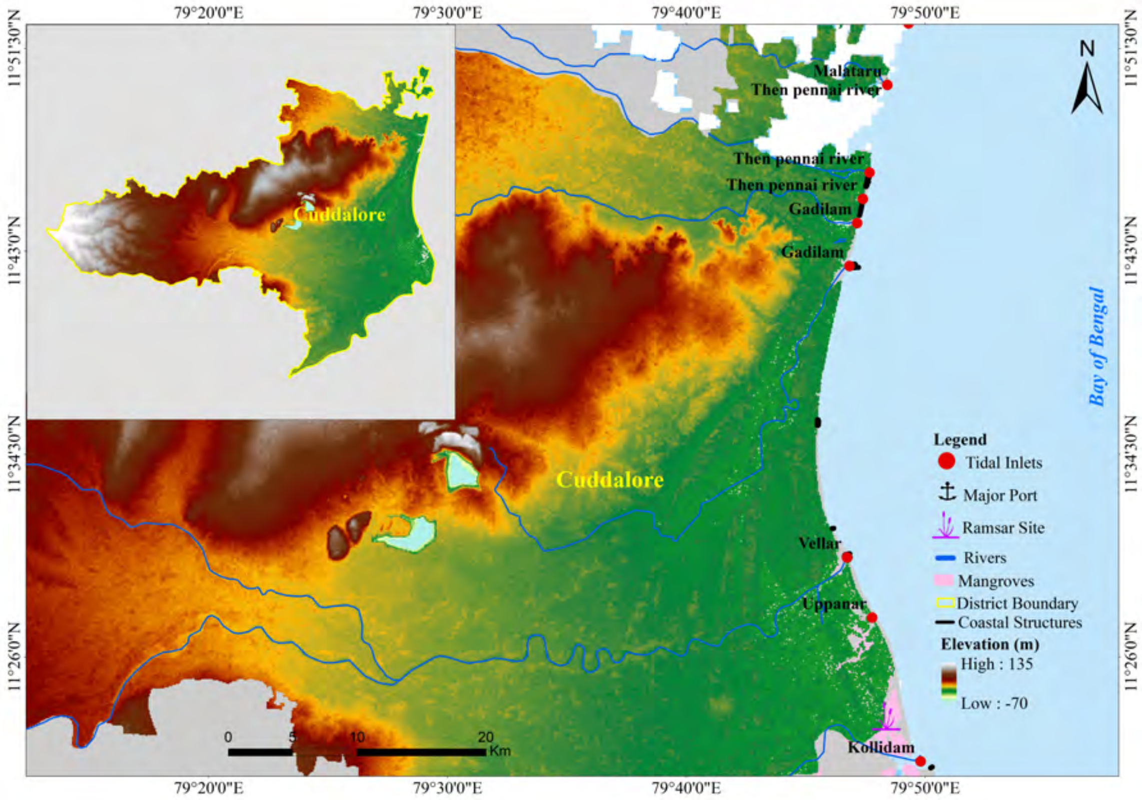


Figure 64 Coastal Profile map of Cuddalore District

The geomorphology of the Cuddalore coastal stretch includes the coastal plain with an average width of 6 kms. Its coastal landforms include strandlines, raised beaches, sand dunes, mangrove swamps and tidal flats with predominantly sandy beaches on the northern side and mangrove swamps on the South. The district occupied by denudation landforms like shallow buried pediment, deep buried pediment, and pediments. The central part of the district is characterized by sedimentary high grounds, elevation >80m of Cuddalore sandstone of Tertiary Age. This zone occupies part of Virudhachalam, Kammapuram, Kurinjipadi, Cuddalore, and Kattumannarkoil taluks. The rest of the area in the district is covered by the eastern coastal plain, which is predominantly occupied by the flood plain of fluvial origin formed under the influence of Penniyar, Vellar, and Coleroon river systems (DHDR-SPC, 2017).

4.5.1 Land use Land Cover (LULC) of Cuddalore District

The LULC assessment conducted for Cudddalore District in 2022 revealed that the dominant land use is agriculture or crop land (78.2 %), followed by water bodies (6.2 %) and Built-up land (Rural) (5.7 %) (Table 41). The district also covers approximately 1158 hectares (0.1 %) of mangrove areas (Figure 65). Cuddalore district is well-known for its extensive mangrove cover, with the Pichavaram mangrove forest serving as a significant ecosystem. Situated between the Vellar estuary to the north and the Coleroon estuary to the south, the forest is a part of the Vellar-Coleroon estuarine complex, encompassing the Killai backwater and Pichavaram mangroves.

Table 41. Land use Land Cover Assessment of Cuddalore District.

S. No.	Land use Land Cover	Area (ha)	% of Total area
1	Built-up land (Urban)	5150	1.4
2	Built-up land (Rural)	20974	5.7
3	Vegetated/Open area	7377	2.0
4	Industrial/ Mining area	8569	2.3
5	Forest	6182	1.7
6	Lagoon, Creeks, Mud Flats, Swamp	1950	0.5
7	Saltpans	28	0.0
8	Waterbody	22922	6.2
9	Sandy Beaches	1258	0.3
10	Wastelands	4872	1.3
11	Agricultural land	288470	78.2
12	Mangroves	1158	0.3
	TOTAL	368915	100.0

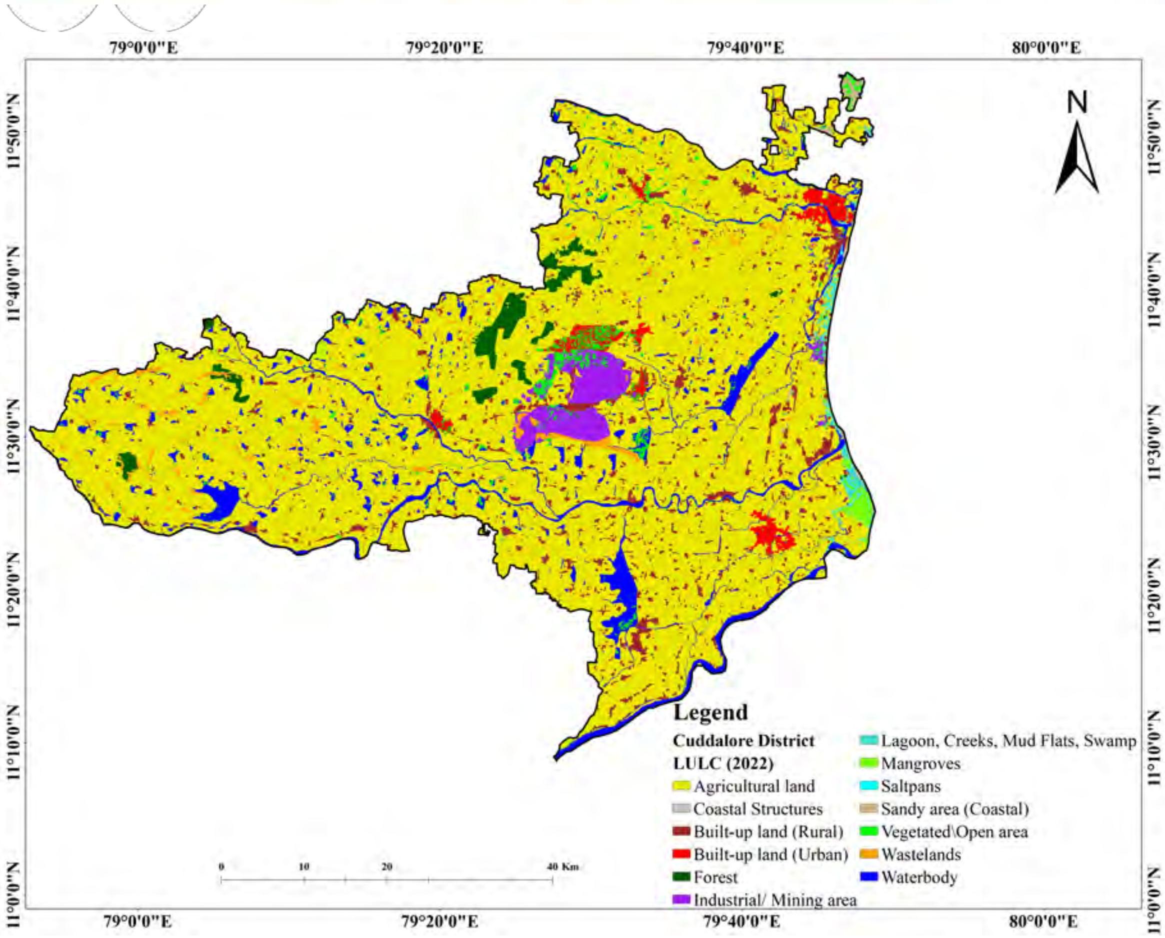


Figure 65 Land use and Land Cover (LULC) of Cuddalore District

4.5.2 Assessment of the Shoreline Change for Cuddalore District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), about 1.82 km of coastal length under high erosion, 4.69 km of coastline under moderate erosion, 5.80 km of coastline under low erosion while 16.21 km under low accretion (Table 42). High and moderate erosion were observed only in the Parangipettai and Cuddalore Blocks (Table 43), indicating vulnerability to shoreline changes. The erosion rate is 2.9 m/year, while the accretion rate is 2.3 m/year. The eroding hotspot villages were identified, and the length was calculated. It is observed that Parangipettai, Periyakumatti, Kothattai, Villiyanallur, Silambimangalam, and Periyappattu villages Parangipettai block and Vanniyar Palayam village of Cuddalore block are highly eroded (Figure 66). The study revealed that about 123 ha of land loss and 79 ha of land gain were observed in the Mayiladuthurai district area over a period of 30 years.

Table 42. Shoreline change assessment of Cuddalore District.

S. No	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Cuddalore	13.13	0.15	0.17	5.28	2.01	4.02	1.16	0.35
2	Kurinchipadi	11.45	-	-	-	3.23	7.73	0.48	-
3	Parangipettai	16.93	1.67	4.52	0.52	0.18	4.46	4.66	0.91
	Total	41.50	1.82	4.69	5.80	5.42	16.21	6.30	1.26

HE - High Erosion, ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

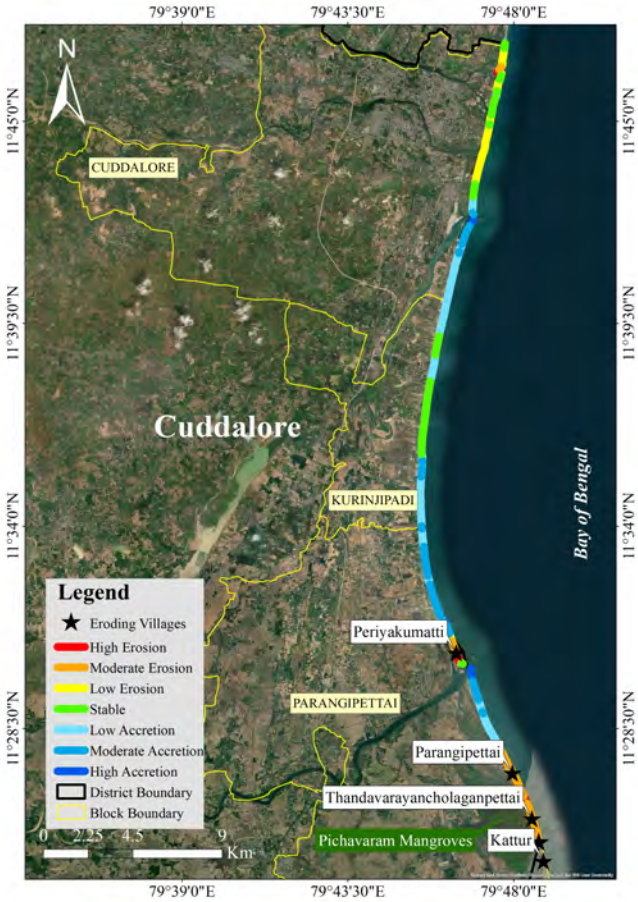


Figure 66 Shoreline Change map of Cuddalore District from 1992 - 2022

Table 43. Eroding hotspots of Cuddalore District.

S.No	District Name	Block Name	Village Name	Length in Km
1	Cuddalore	Parangipettai	Periyakumatti	1.16
2			Parangipettai	2.58
3			Thandavarayancholaganpettai	2.41

Table 44. Accretion dominant villages in Cuddalore District.

S.No	District Name	Block Name	Village Name	Length in Km
1	Cuddalore	Cuddalore	Vanniyar Palayam	1.34
2		Parangipettai	Periyappattu	1.21
3			Silambimangalam	1.28
4			Villiyanallur	1.27
5			Kothattai	1.37
6			Periyakumatti	2.45
7			Parangipettai	2.65

4.5.3 SLR Projections and Coastal Inundation in Cuddalore District

The projection of the total trend of SLR for the Cuddalore coast based on the SSP2 4.5 scenario (Medium Projection) for the near century is estimated as an average of 20.3 cm (Figure 67). The coastal inundation due to the rise in sea level is projected to be about 359 ha. The Lagoon, Creeks, Mudflats, swamps, Agricultural land, and Waterbody Sandy Beaches are at high risk due to inundation (Figure 68).

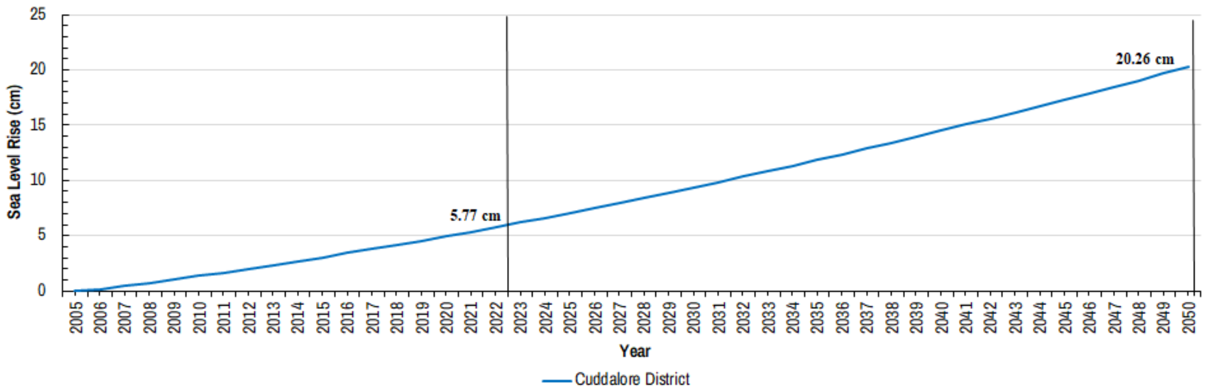


Figure 67 Projected SLR of Cuddalore District under SSP2- 4.5 (cm) for the Near Century

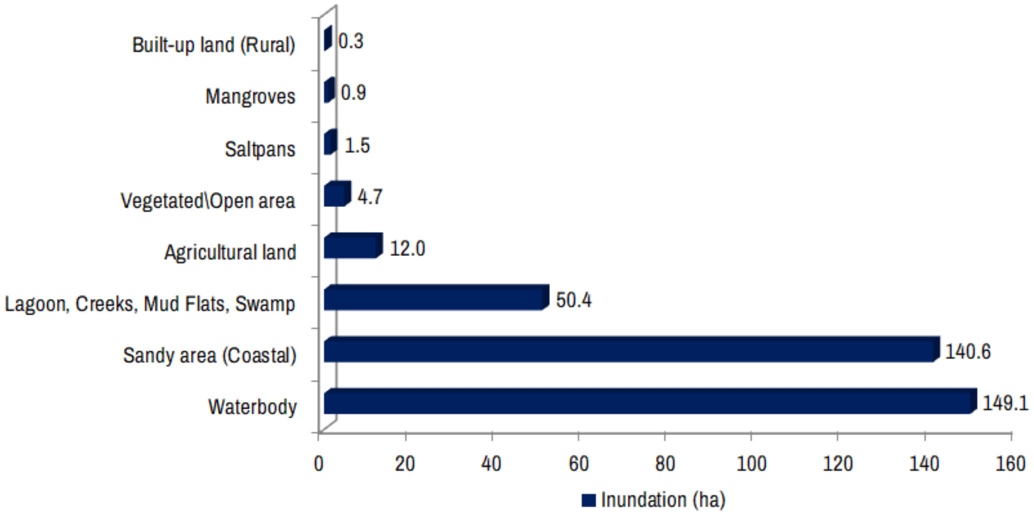


Figure 68 Impact of coastal inundation on land use land cover of Cuddalore District.

4.5.4 Coastal Risk Assessment of Cuddalore District

The coastline of Cuddalore is under a very high category and highly vulnerable to multiple hazards, with 23.1 km in the base period and 26.8 km in the projected period being particularly susceptible. In terms of vulnerability and exposure, the Cuddalore most of the coastline is classified as high - very high (Figure 69). Consequently, the risk for the coastline has increased both in the baseline and projected periods from 21.9 km to 26.82 km (Table 45).

Table 45. Integrated Coastal Risk Assessment for Cuddalore District (km).

S. No.	Cuddalore	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	1.9	1.4	0.4	8.0	4.7	3.2
2	Low	6.1	5.1	3.6	2.5	9.5	4.9
3	Moderate	11.2	9.1	2.7	3.0	6.2	8.0
4	High – Very High	23.1	26.8	35.7	28.9	21.9	26.2
	Total	42.3	42.3	42.3	42.3	42.3	42.3

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

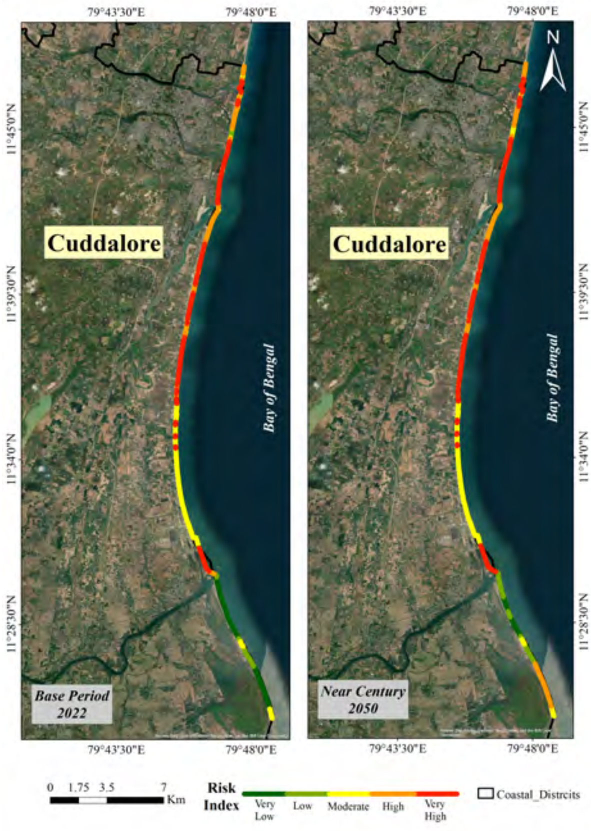


Figure 69 Coastal Risk Index map of Cuddalore District

4.6 Mayiladuthurai

Mayiladuthurai extends between 11°06'06.5"N latitude 79°39'09.3"E longitude (Figure 70). The district is part of the Coromandel coast and has three blocks, such as Kollidam, Sirkali, and Sembanarkoil, covering 70.9 km of coastal length. It is situated between the Kollidam River in the north and Karaikal in the south. Mayiladuthurai coastal- plain covering almost the entire district with beaches, beach ridges, mud flats, swamps, and back waters along the coastal stretch (NCRC, 2007).

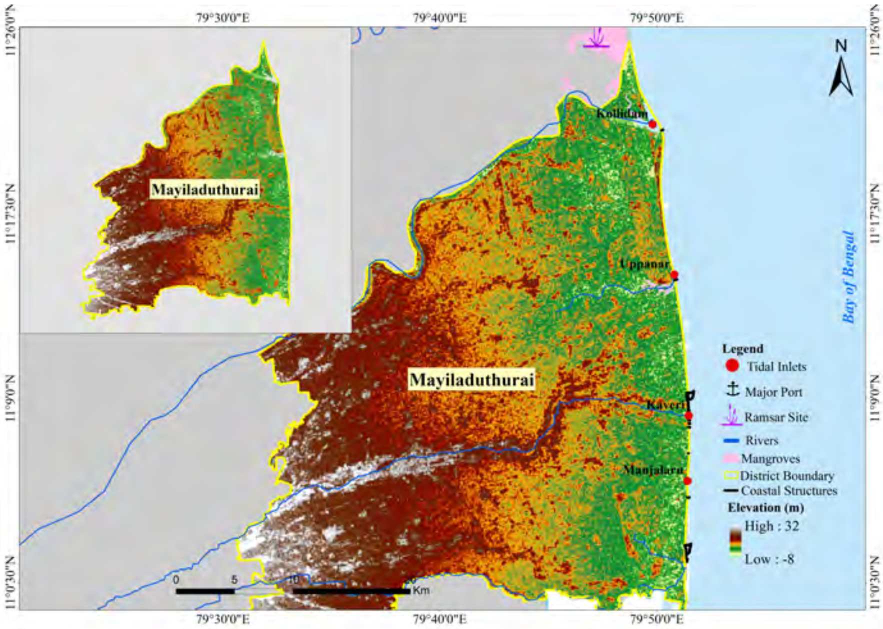


Figure 70 Coastal Profile map of Mayiladuthurai District

4.6.1 Land use Land Cover (LULC) of Mayiladuthurai District

The LULC assessment conducted for Mayiladuthuai District in 2022 revealed that the dominant land use is agriculture or crop land (76.3 %), followed by Built-up land (Rural) (12.9 %) and water bodies (4.8 %) (Table 46). The district also covers approximately 699 hectares (0.1 %) of mangrove areas (Figure 71).

Table 46. Land use Land Cover Assessment of Mayiladuthurai District.

S. No.	Land use Land Cover	Area (ha)	% of Total area
1	Built-up land (Urban)	1863	1.6
2	Built-up land (Rural)	15262	12.9
3	Vegetated/Open area	1188	1.0
4	Industrial/ Mining area	34	0.0
5	Forest	15	0.0
6	Lagoon, Creeks, Mud Flats, Swamp	2807	2.4
7	Saltpans	1	0.0
8	Waterbody	5710	4.8
9	Sandy Beaches	388	0.3
10	Wastelands	17	0.0
11	Agricultural land	90285	76.3
12	Mangroves	699	0.6
TOTAL		118270	100.0

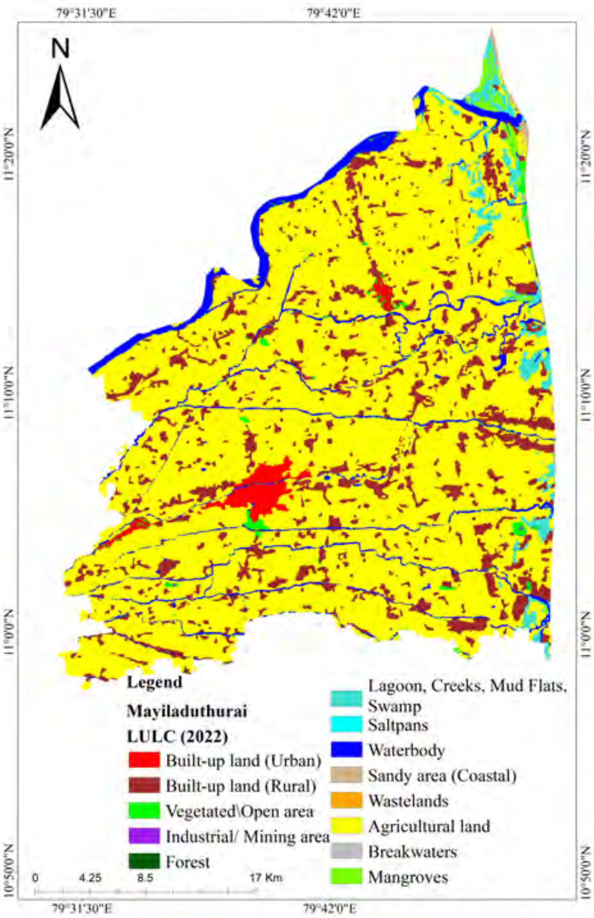


Figure 71 Land use and Land Cover (LULC) of Mayiladuthurai District

4.6.2 Assessment of the Shoreline Change for Mayiladuthurai District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), about 3.69 km of coastal length under high erosion, 5.49 km of coastline under moderate erosion, 19.9 km of coastline under low erosion while 8.73 km under low accretion (Table 47). High and moderate erosion were observed only in the Kollidam Sirkali and Sembanarkoil Blocks, indicating vulnerability to shoreline changes (Table 48). The erosion rate is 2.7 m/year, while the accretion rate is 1.1 m/year. The eroding hotspot villages were identified, and the length was calculated (Figure72). It is observed that Pudhupattinam, Keezhaiyur, Kattur, Perunthottam, Kaalamanallur, Marudampallam, and Vanagiri villages are highly eroded, while Sathangudy villages observed with high accretion (Table 49). The study revealed that about 205 ha of land loss and 67 ha of land gain were observed in the Mayiladuthurai district area over a period of 30 years.

Table 47. Shoreline change assessment of Mayiladuthurai District.

S. No.	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Kollidam	21.32	2.92	2.60	3.80	4.32	6.96	0.71	-
2	Sirkali	13.91	0.62	2.77	7.46	2.40	0.66	-	-
3	Sembanarkoil	14.54	0.15	0.13	8.64	4.35	1.11	0.17	-
4	Total	49.77	3.69	5.49	19.90	11.07	8.73	0.89	-

HE - High Erosion,ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

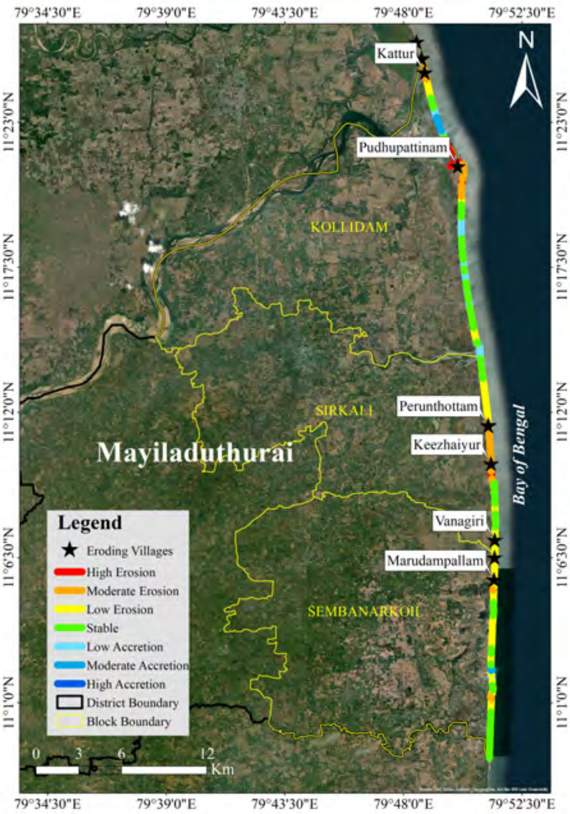


Figure 72 Shoreline Change map of Mayiladuthurai District from 1992 - 2022

Table 48. Eroding hotspots of Mayiladuthurai District.

S. No.	District Name	Block Name	Village Name	Length in Km
1	Mayiladuthurai	Kollidam	Kattur	1.95
2			Pudhupattinam	4.7
3		Sirkali	Perunthottam	1.75
4			Keezhaiyur	3.56
5			Vanagiri	0.84
6		Sembanarkoil	Kaalamanallur	1.61
7			Marudampallam	1.5

Table 49. Accretion-dominant villages in the Mayiladuthurai District.

S. No.	District Name	Block Name	Village Name	Length in Km
1	Mayiladuthurai	Sembanarkoil	Sathangudy	1.03

4.6.3 SLR Projections and Coastal Inundation in Mayiladuthurai District

The projection of the total trend of SLR for the Mayiladuthurai coast based on the SSP2 4.5 scenario (Medium Projection) for the near century is estimated as an average of 20.3 cm (Figure 73). The coastal inundation due to the rise in sea level is projected to be about 398 ha. The Lagoon, Creeks, Mudflats, Swamps, Agricultural land, and Waterbody Sandy Beaches are at high risk due to inundation (Figure 74).

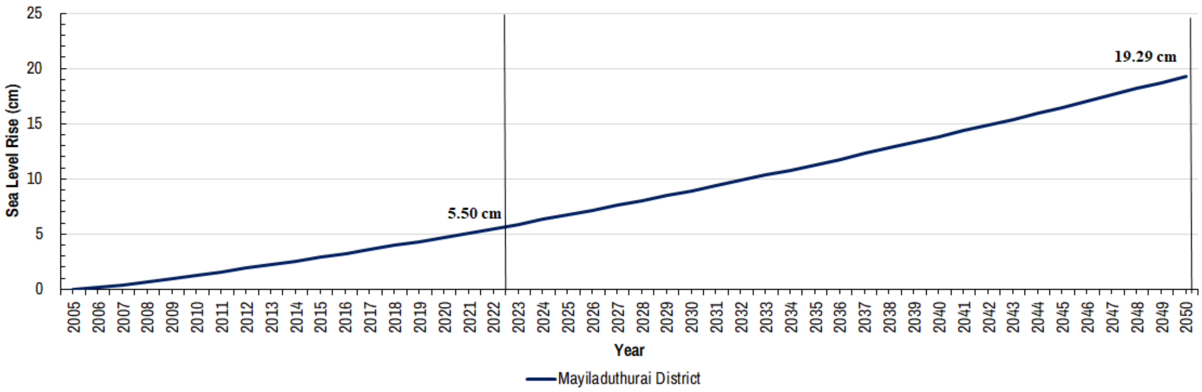


Figure 73 Projected SLR of Mayiladuthurai District under SSP2- 4.5 (cm) for the Near Century

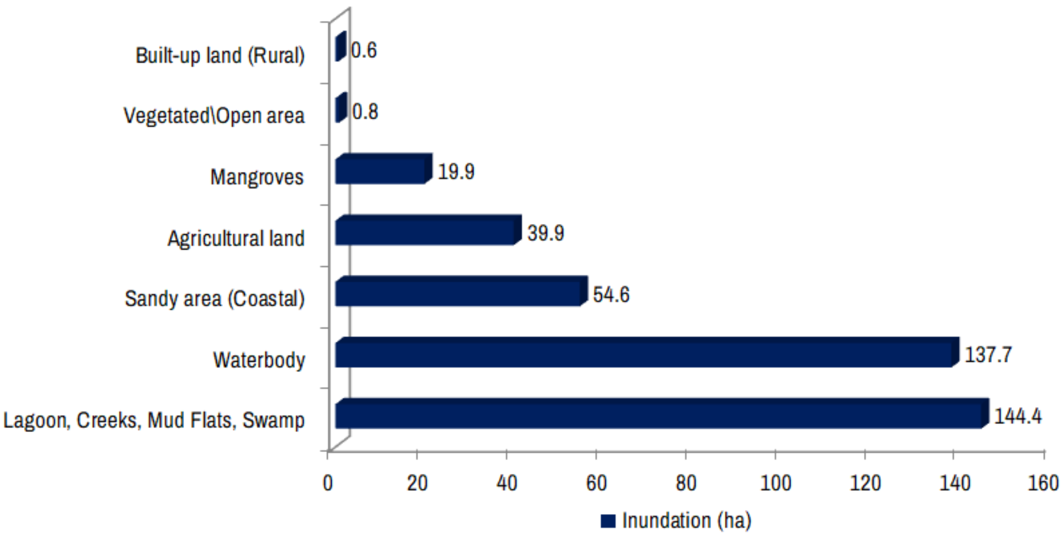


Figure 74 Impact of coastal inundation on land use land cover of Mayiladuthurai District.

4.6.4 Coastal Risk Assessment of Mayiladuthurai District

The coastline of Mayiladuthurai is under a very high category and highly vulnerable to multiple hazards, with 26.7 km in the baseperiod and 30.9 km in the projected period being particularly susceptible (Table 50). In terms of vulnerability and exposure, the Mayiladuthurai coast is classified as very high. Consequently, the risk for the coastline has increased both in the baseline and projected periods from 24 km to 30 km (Figure 75).

Table 50. Integrated Coastal Risk Assessment for Mayiladuthurai District (km).

S. No.	Mayiladuthurai	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	0.1	0.1	0.2	15.4	9.3	5.1
2	Low	16.0	13.3	3.1	20.3	3.2	4.2
3	Moderate	7.8	6.3	10.3	10.0	14.0	11.2
4	High – Very High	26.7	30.9	36.9	4.8	24.0	30.0
	Total	50.5	50.5	50.5	50.5	50.5	50.5

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

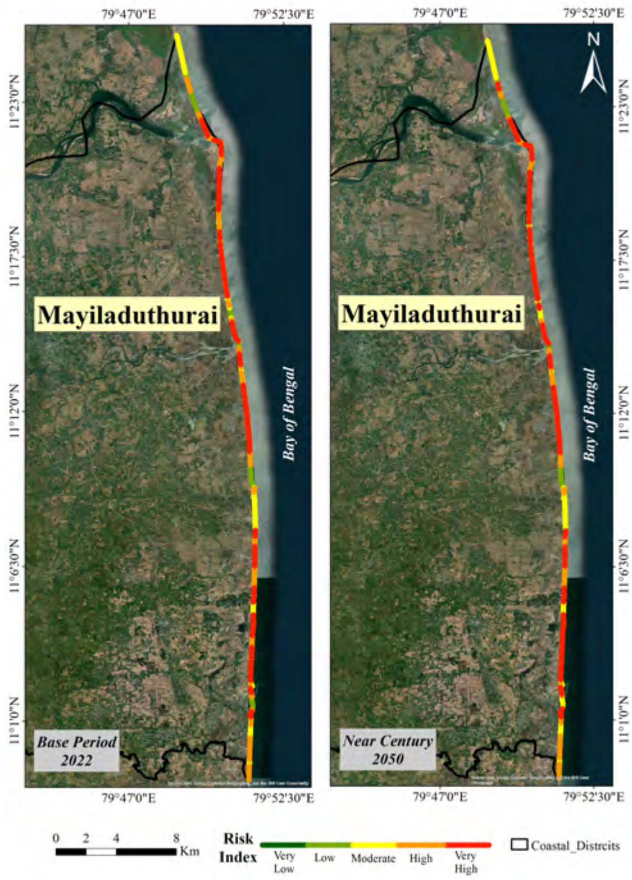


Figure 75 Coastal Risk Index map of Mayiladuthurai District

4.7 Nagapattinam

Nagapattinam extends between 10°10' and 11°20' N latitude and between 79°15' and 79°50' longitude (Figure 76). The district is part of the Coromandel Coast and has four blocks: Nagapattinam, Keelaiyur, Thalainayar, and Vedaranyam, covering 54.0 km of coastal length. The district is highly prone to cyclones, and so far, 5 severe cyclonic storms hit the district. The district is situated in the deltaic region of the Cauvery River. Kollidam River forms the northern boundary of the district, and tributaries and branches of the Cauvery River are Arasalar, Tirumalairajanar, Vettar, and Vennar. Marine fishing is practised in 53 coastal villages of the district. Velankanni is the most visited pilgrim centres situated on the shores of the Bay of Bengal. Kodiakkarai, or Point Calimere, is situated in the Palk Strait. This Wild Life Sanctuary boasts of mammals like blue buck, spotted deer, wild boar, semi-wild ponies, bonnet macaque, and water birds like flamingos, ibises, herons, and spoonbills. Sea turtles, star tortoises, vipers, marsh crocodiles, etc., are some of the reptiles. Fish, dolphins, dugongs, sea lions, and sea cows are occasionally found here. Besides, it is where the occurrence of varieties of corals is found. According to the Tamil Nadu Fisheries Department in 2022, the district has a fisherman population of 40,586 individuals.

The deltaic plains are found near the confluence of River Coleroon with sea in the east and also in the south. Flood plain deposits are observed along the river courses (NCRC, 2007). The stretch consists of a narrow region of sandy beach along the coast in the delta region of the Cauvery River. There are Salt pans as well as permanent Vedaranyam swamp region with mangrove forest (Anuradha, 2018). The terrain of Nagapattinam is generally plain with a gradual slope of 1.2 degrees. The topographical slope is towards the east and the southeast. It has an average elevation of 6 m above mean sea level (DTCP, 2022).

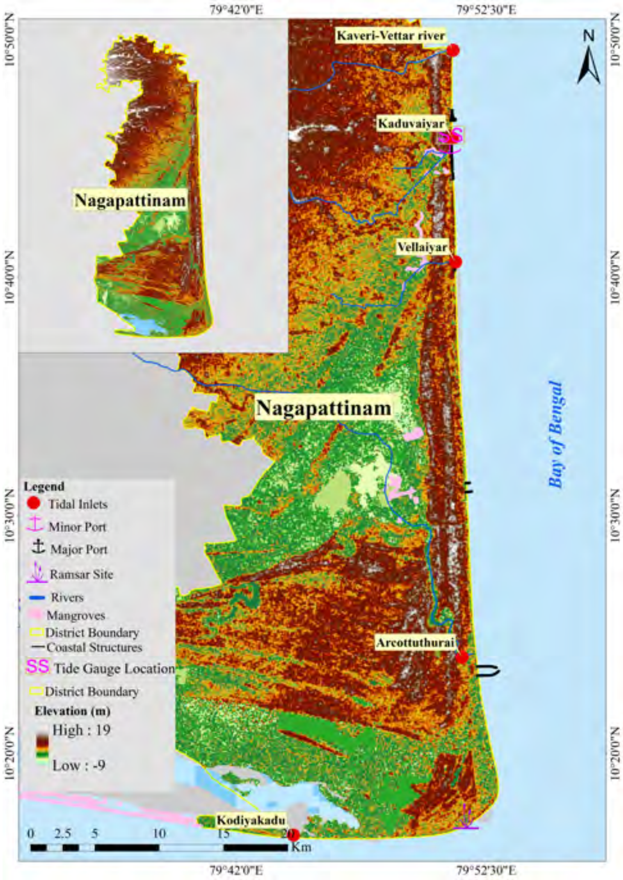


Figure 76 Coastal Profile map of Nagapattinam District

4.7.1 Land use Land Cover (LULC) of Nagapattinam District

The LULC assessment conducted for Nagapattinam District in 2022 revealed that the dominant land use is agriculture or crop land (67.7 %), followed by Lagoon, Creeks, Mud Flats, Swamp (13.5 %), Built-up land (Rural) (7 %), and water bodies (5.8 %) (Table 51). The district also covers approximately 699 hectares (0.1 %) of mangrove areas (Figure 77). The Saltpan area is around 4139 ha (3%). Nagapattinam considered the second largest producer in the state, produce 2.50 lakh tons of salt every year.

Table 51. Land use Land Cover Assessment of Nagapattinam District.

S. No.	Land use Land Cover	Area (ha)	% of Total area
1	Built-up land (Urban)	1294	0.9
2	Built-up land (Rural)	9841	7.0
3	Vegetated/Open area	1683	1.2
4	Industrial/ Mining area	106	0.1
5	Forest	7	0.0
6	Lagoon, Creeks, Mud Flats, Swamp	18946	13.5
7	Saltpans	4139	3.0
8	Waterbody	8147	5.8
9	Sandy Beaches	588	0.4
10	Wastelands	109	0.1
11	Agricultural land	94789	67.7
12	Mangroves	314	0.2
TOTAL		139968	100.0

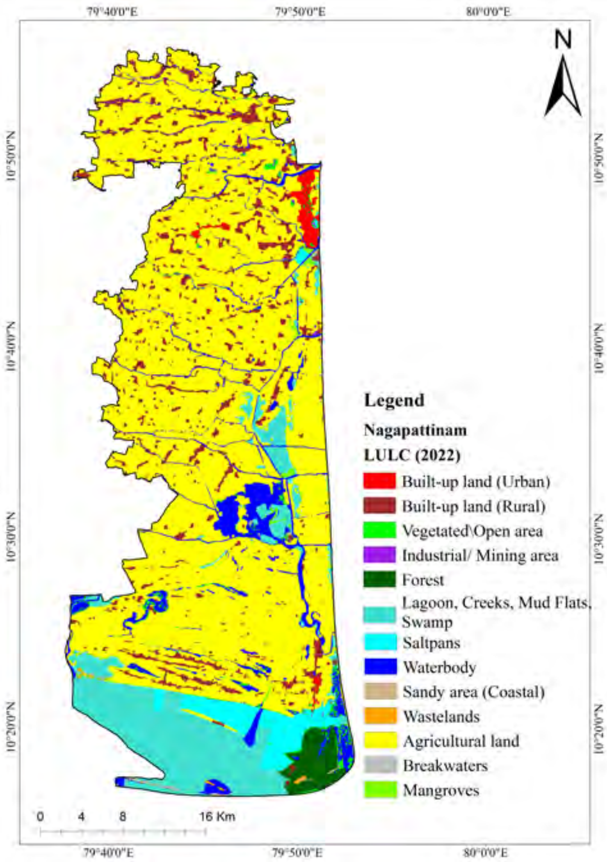


Figure 77 Land use and Land Cover (LULC) of Nagapattinam District

4.7.2 Assessment of the Shoreline Change for Nagapattinam District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), about 1.75 km of coastal length under high erosion, 4.26 km of coastline under moderate erosion, 19.97 km of coastline low moderate erosion while 4.43 km under high accretion (Table 52). High erosion and moderate erosion were observed only in the Vedaranyam Block, indicating the vulnerability of the Vedaranyam block to shoreline changes. The eroding hotspot villages were identified, and the length was calculated. It is observed that Kodiayakarai, Serttaikkadu Creek villages of Vedaranyam block are highly eroded (Table 53), while Vellappallam, Serttaikkadu Creek, Kodiayakarai, Vedaranyam Part- 1, and Agasthiyampalli villages observed with high accretion (Table 54) (Figure 78). The erosion rate is 2 m/year, while the accretion rate is 2.7 m/year. The study revealed that about 198 ha of land loss and 256 ha of land gain were observed in the Nagapattinam district area over a period of 30 years.

Table 52. Shoreline change assessment of Nagapattinam District (km).

S. No.	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Nagapattinam	14.96	-	-	5.93	5.89	2.77	0.37	-
2	Keelaiyur	15.54	-	-	1.02	1.20	12.88	0.45	-
3	Thalainayar	8.50	-	-	-	0.47	4.96	2.74	0.33
4	Vedaranyam	42.90	1.75	4.26	13.01	3.83	11.70	4.24	4.10
	Total	81.90	1.75	4.26	19.97	11.38	32.31	7.79	4.43

HE - High Erosion,ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

Table 53. Eroding hotspots of Nagapattinam District

S. No.	District Name	Block Name	Village Name	Length in Km
1	Nagapattinam	Vedaranyam	Kodiayakarai	3.28
2			Serttaikkadu Creek	7.72

Table 54. Accretion dominant villages in Nagapattinam District.

S. No.	District Name	Block Name	Village Name	Length in Km
1	Nagapattinam	Thalainayar	Vellappallam	2.57
2		Vedaranyam	Vedaranyam Part- 1	1.41
3			Agasthiyampalli	1.41
4			Kodiayakarai	2.07
5			Serttaikkadu Creek	2.44

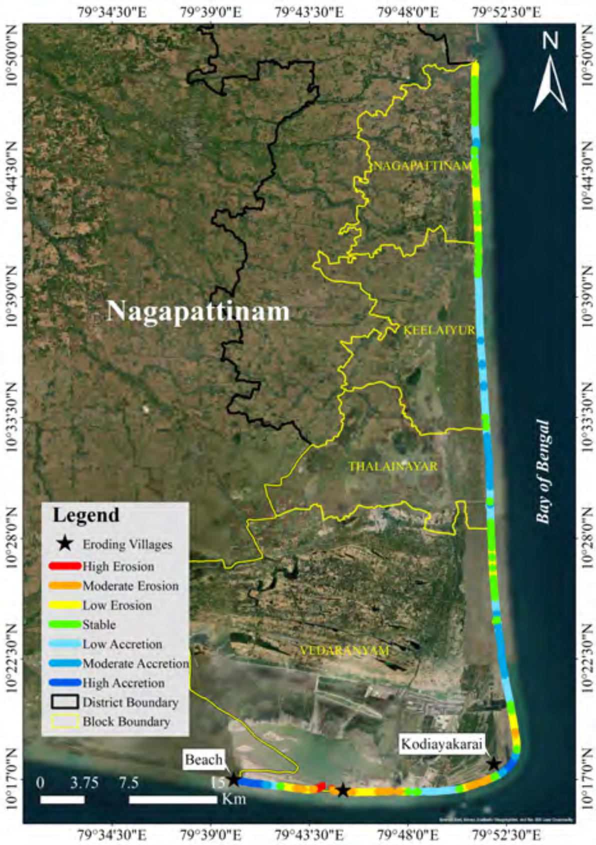


Figure 78 Shoreline Change map of Nagapattinam District from 1992 – 2022

4.7.3 SLR Projections and Coastal Inundation in Nagapattinam District

The projection of the total trend of SLR for the Nagapattinam coast based on the SSP2 4.5 scenario (Medium Projection) for the near century is estimated as an average of 20.3 cm (Figure 77). The coastal inundation due to the rise in sea level is projected to be about 10011 ha. The Lagoon, Creeks, Mud Flats, Swamp, Saltpans, Agricultural land, and Waterbody Sandy Beaches are at high risk due to inundation (Figure 79).

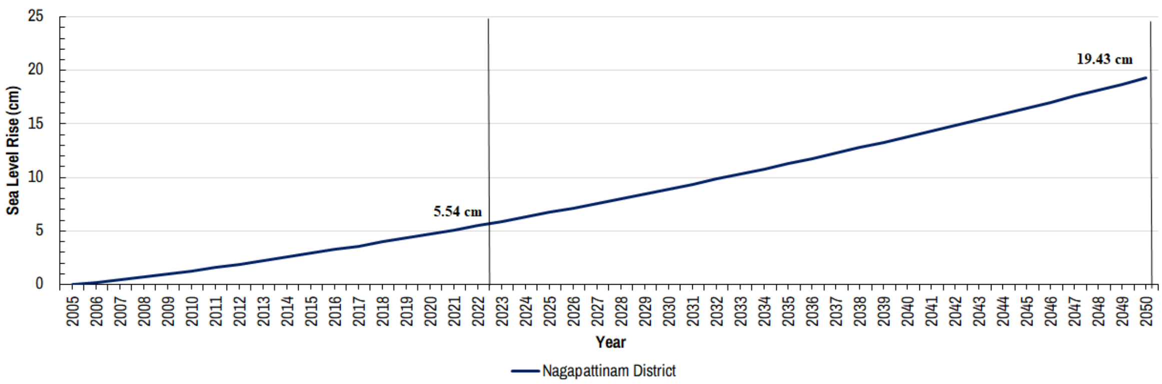


Figure 79 Projected SLR of Nagapattinam District under SSP2- 4.5 (cm) for the Near Century

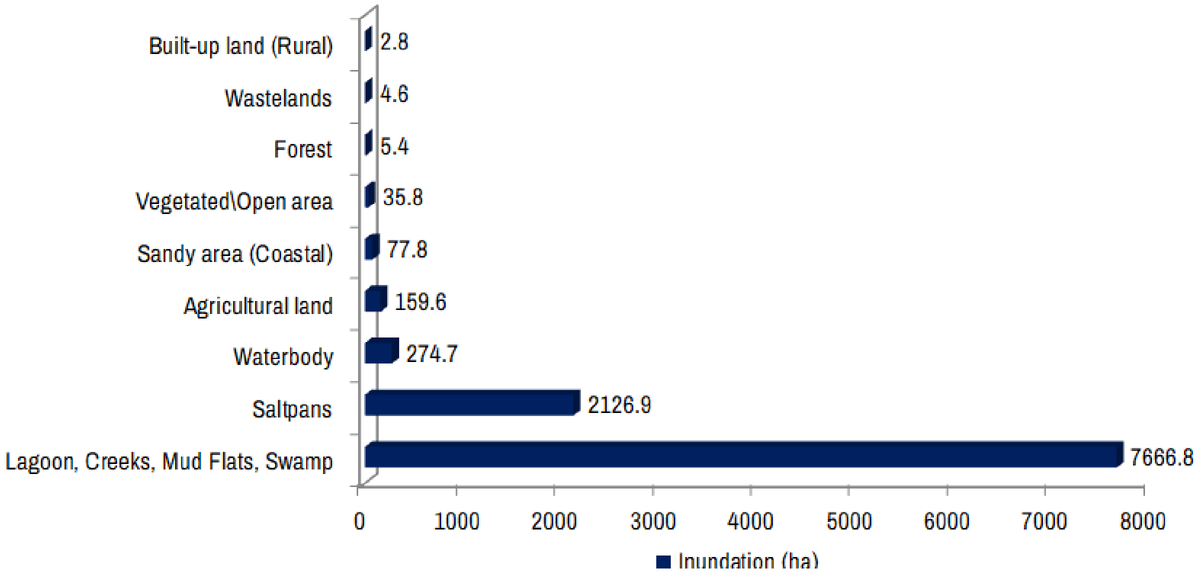


Figure 80 Impact of coastal inundation on land use land cover of Nagapattinam District.

4.7.4 Coastal Risk Assessment of Nagapattinam District

The coastline of Nagapattinam is under a very high category and highly vulnerable to multiple hazards, with 76.7 km in the base period and 77 km in the projected period being particularly susceptible. In terms of vulnerability and exposure, the Nagapattinam coast is classified as very high (Figure 80). Consequently, the risk for the coastline has increased both in the baseline and projected periods from 60.1 km to 6.34 km (Table 55).

Table 55. Integrated Coastal Risk Assessment for Nagapattinam District (km).

S. No.	Nagapattinam	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	0.0	0.0	0.3	7.1	1.8	1.5
2	Low	2.8	2.7	0.1	34.8	12.2	6.3
3	Moderate	4.1	3.9	2.3	32.2	9.5	12.3
4	High – Very High	76.7	77.0	80.8	9.4	60.1	63.4
	Total	83.5	83.5	83.5	83.5	83.5	83.5

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

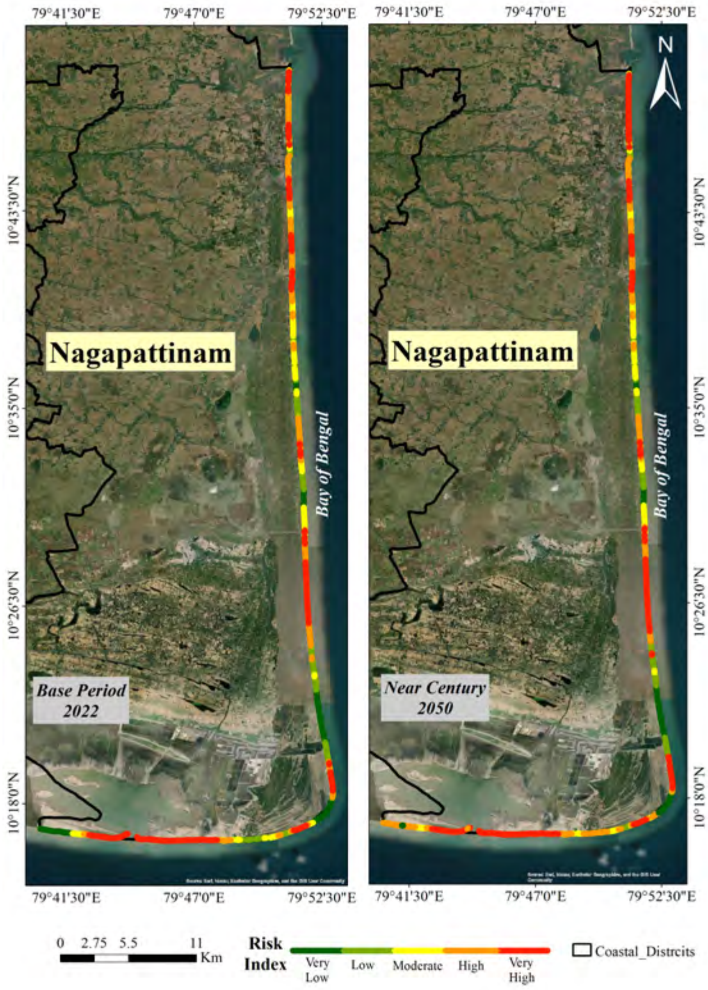


Figure 81 Coastal Risk Index map of Nagapattinam District

4.8 Tiruvarur

It lies between 10° 20' to 11°07' North latitude and 79°15' to 79°45' East longitude (Figure 82). The district is part of Palk Bay and has a Muthupettai block covering 47.2 km of coastal length. The district has good fishing potential in view of its rich coastal area. According to the Tamil Nadu Fisheries Department in 2022, the district has a fisherman population of 5591 individuals. Muthupet mangrove forest is one of the Ramsar sites in Tamil Nadu, covering an area of approximately 13,500 ha, of which only 4% is occupied by well-grown mangroves. The rivers Paminiyar, Koraiyar, Kilaithankiyar, Marakkakoraiyar and other tributaries of the river Cauvery flow through Muthupet and adjacent villages. At the tail end, they form a lagoon before meeting the sea. Avicennia marina is the most abundant mangrove species in the Muthupettai Mangrove forest.

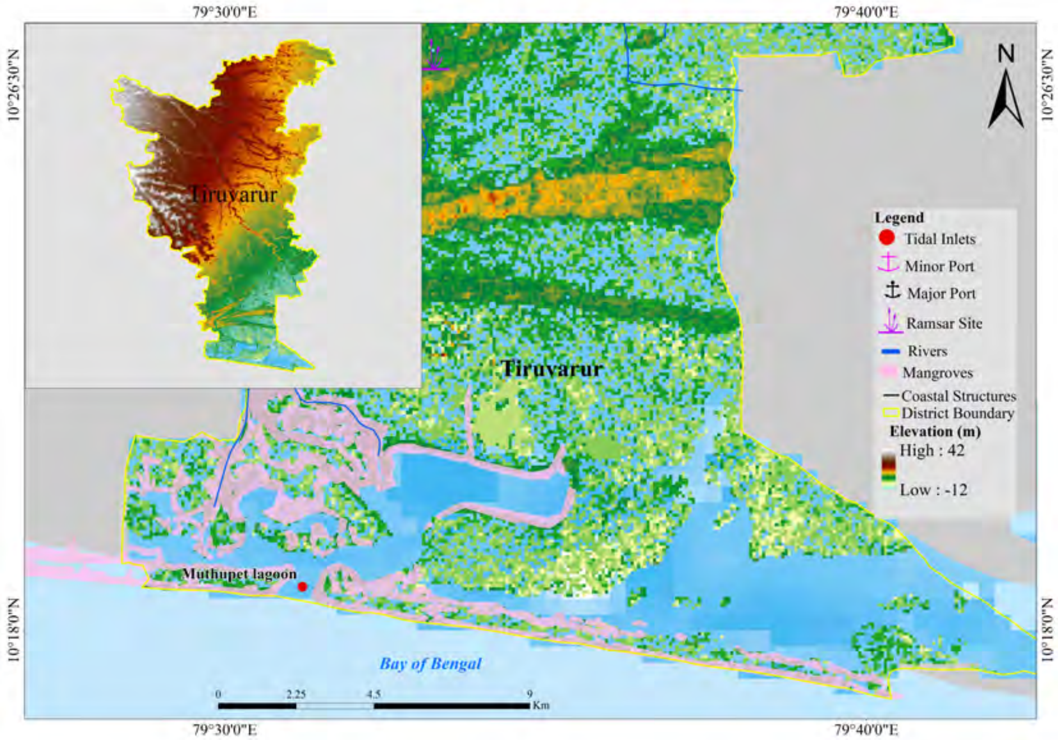


Figure 82 Coastal Profile map of Tiruvarur District

Tiruvarur can be divided into three regions from the topography and flora point of view. They are the alluvial regions: land areas on the banks of rivers and canal in the form of narrow strips. The lateritic region: This region contains mostly thorny scrub jungles, tropical thorn forests and tropical dry evergreen forests. The coastal regions: This zone contains causurina plantations, mangrove scrub, mangrove forest and southern thorn scrub jungle. The entire stretch of coastal mangroves with lagoons and back waters lying along the coast fall in this category (DHDR-SPC, 2017).

4.8.1 Land use Land Cover (LULC) of Tiruvarur District

The LULC assessment conducted for Tiruvarur District in 2022 revealed that the dominant land use is agriculture or crop land (78.1 %), followed by Built-up land (Rural) (10%), Lagoon, Creeks, Mud Flats, Swamp (5.8 %), and water bodies (3.7 %) (Table 56). The district also covers approximately 1220 hectares (0.5 %) of mangrove areas (Figure 83).

Table 56. Land use Land Cover Assessment of Tiruvarur District.

S. No.	Land use Land Cover	Area (ha)	% of Total area
1	Built-up land (Urban)	1471	0.6
2	Built-up land (Rural)	23279	10.1
3	Vegetated/Open area	1969	0.9
4	Industrial/ Mining area	39	0.02
5	Forest	1	0.0003
6	Lagoon, Creeks, Mud Flats, Swamp	13456	5.8
7	Saltpans	36	0.0
8	Waterbody	8589	3.7
9	Sandy Beaches	1	0.0003
10	Wastelands	424	0.2
11	Agricultural land	179901	78.1
12	Mangroves	1220	0.5
TOTAL		230384	100.0

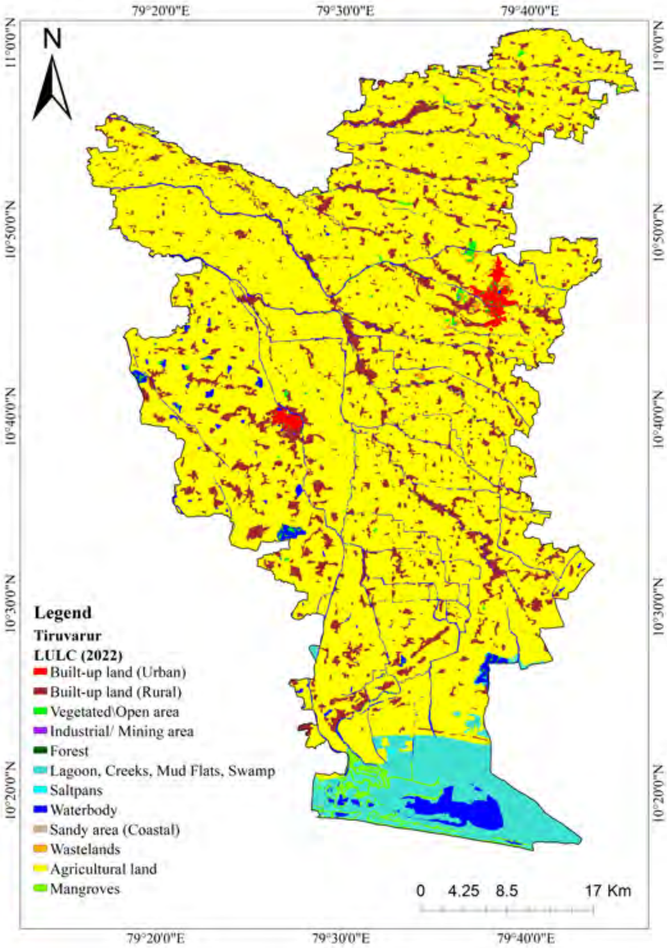


Figure 83 Land use and Land Cover (LULC) of Tiruvarur District

4.8.2 Assessment of the Shoreline Change for Tiruvarur District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), about 2.18 km of coastal length was under low erosion, while 7.41 km was under low accretion (Table 57). The erosion rate is 1.3 m/year, while the accretion rate is 2.5 m/year. The eroding hotspot village was identified, and the length was calculated. It is observed that the beach village of Muthupettai block was 1.31km of coastline highly eroded (Table 58), while 4.13 km coastline was accreting (Table 59) (Figure 84). The study revealed that about 24 ha of land loss and 108 ha of land gain were observed in the Tiruvarur district area over a period of 30 years.

Table 57. Shoreline change assessment of Tiruvarur District.

S.No.	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Muthupettai	22.44	-	0.45	2.18	7.19	7.41	2.27	2.94
2	Total	22.44	-	0.45	2.18	7.19	7.41	2.27	2.94

HE - High Erosion,ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

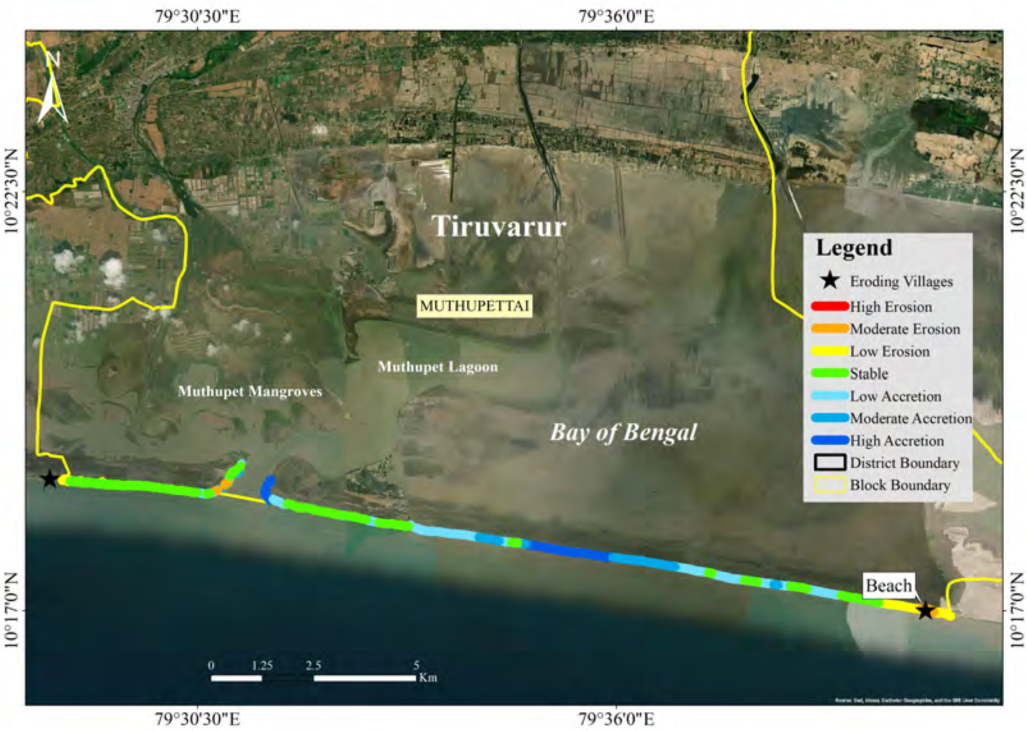


Figure 84 Shoreline Change map of Tiruvarur District from 1992 - 2022

Table 58. Eroding hotspots of Tiruvarur District.

S. No	District Name	Block Name	Village Name	Length in Km
1	Tiruvarur	Muthupettai	Beach	1.31

Table 59. Accretion dominant villages in Tiruvarur District.

S. No	District Name	Block Name	Village Name	Length in Km
1	Tiruvarur	Muthupettai	Beach	4.13

4.8.3 SLR Projections and Coastal Inundation in Tiruvarur District

The projection of the total trend of SLR for the Tiruvarur coast based on the SSP2 4.5 scenario (Medium Projection) for the near century is estimated as an average of 19.7 cm (Figure 85). The coastal inundation due to the rise in sea level is projected to be about 11794 ha. The inundation effect is mostly on agricultural land and Lagoon, Creeks, Mudflats and swamps (Figure 86).

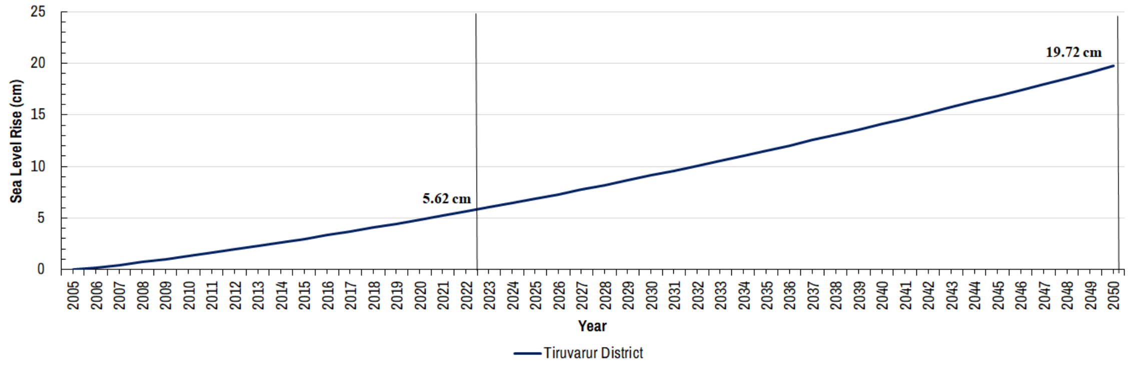


Figure 85 Projected SLR of Tiruvarur District under SSP2- 4.5 (cm) for the Near Century

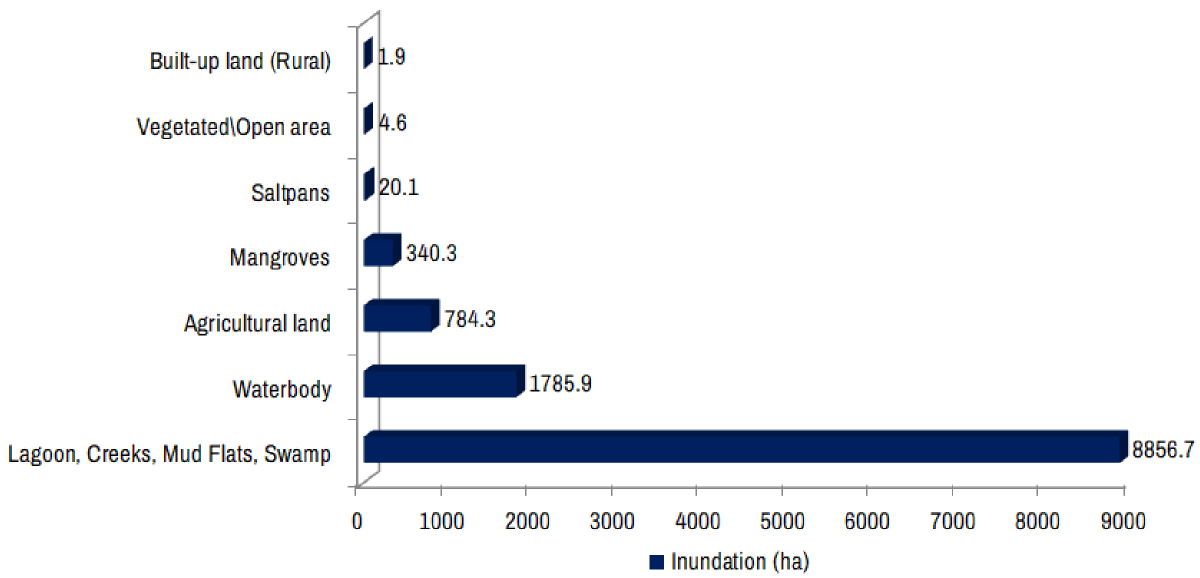


Figure 86 Impact of coastal inundation on land use land cover of Tiruvarur District.

4.8.4 Coastal Risk Assessment of Tiruvarur District

The coastline of Tiruvarur falls under the high vulnerability category and is highly susceptible to multiple hazards, with 15.3 km in the base period and 16 km in the projected period being particularly susceptible (Table 60). In terms of vulnerability, the district under very high vulnerable category with 22.3 km of coastline under high – very high category (Figure 87). Therefore, the risk for the coastline has increased both in the baseline and projected periods from 18.8 km to 19.1 km.

Table 60. Integrated Coastal Risk Assessment for Tiruvarur District (km).

S. No.	Tiruvarur	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	0.2	0.2	0.0	0.0	0.9	0.7
2	Low	1.8	1.6	0.0	0.0	1.9	1.5
3	Moderate	6.1	5.6	1.1	10.2	1.8	2.0
4	High – Very High	15.3	16.0	22.3	13.2	18.8	19.1
	Total	23.4	23.4	23.4	23.4	23.4	23.4

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

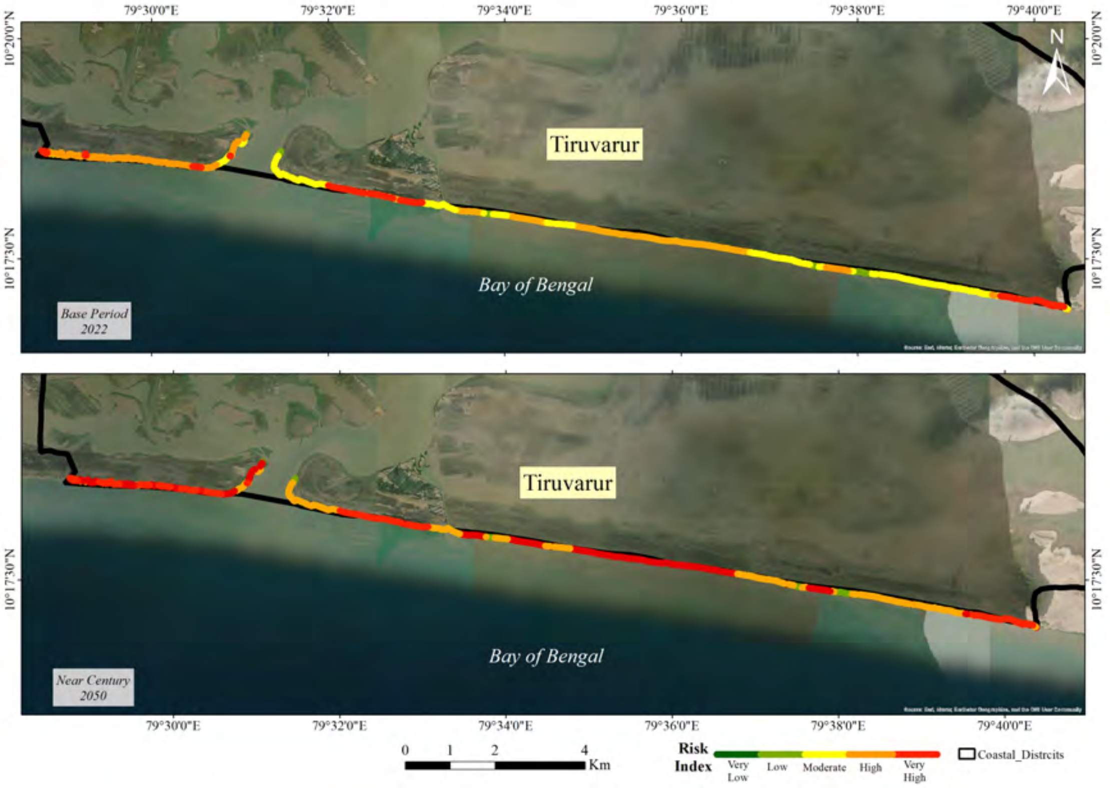


Figure 87 Coastal Risk Index map of Tiruvarur District

4.9 Thanjavur

Thanjavur district lies between 9º 50’ and 11º 25’ North latitude and 78º 45’ and 79º 25’ East longitude (Figure 88). The district is part of Palk Bay and has two coastal blocks, Pattukottai, Sethubavachatram -1 and Sethubavachatram -2, covering 45.1 km of coastal length. The river Cauvery and its tributaries are the most remarkable features of Thanjavur district. Thanjavur district occupies a 45.1 km stretch in Palk Strait with 27 fishing villages in the district from Thambikkottai in Pattukkottai taluk in the North and Sembagamadevi Pattinam in Peravurani taluk in the South. According to the Tamil Nadu Fisheries Department in 2022, the district has a fisherman population of 13674 individuals.

Seagrass is the coastal blue carbon ecosystem found in this region between 9º 20’ to 10º 17’ North latitude and 78º 59’ to 79º 20’ East longitude. It is densely spread across Athirampattinam to Pamban. It is situated in the offshore of 8 km perpendicular to the shoreline.

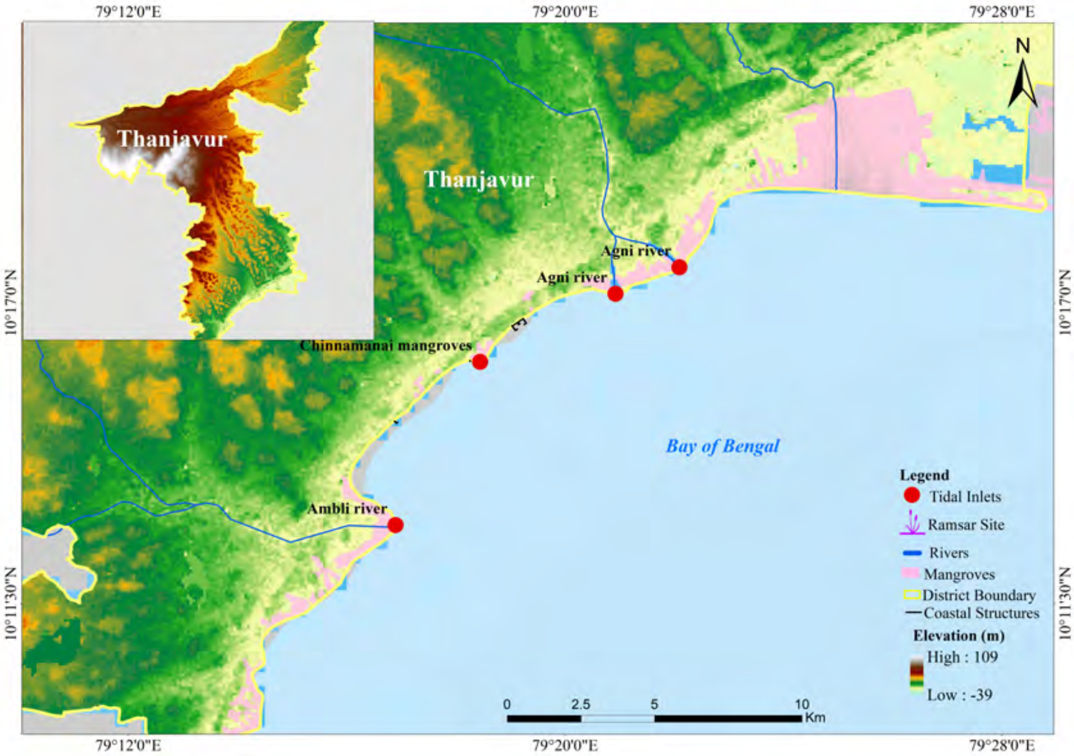


Figure 88 Coastal Profile map of Thanjavur District

The Thanjavur district mostly covered by an alluvial plain, with the southern part of the district characterized by beach ridges. In the Pattukottai area, located in the southern side of the district, brackish water is commonly found. The coastal area of Pattukottai taluk consists of mud-flat regions, which are swampy areas permanently filled with tidal water. The sediment constituents of these mud flats come from mangrove debris and organic waste. Moving towards the sea, fine silts and mud tend to increase. The pediplain areas are situated in the southern side of the Pattukottai area, while the salt flats are generally located in the southeastern part of the district along the coast. The coastal plain areas are primarily concentrated in the southern part of the district, particularly in Pattukottai taluk (Punithavathi et al., 2024).

4.9.1 Land use Land Cover (LULC) of Thanjavur District

The LULC assessment conducted for Tiruvarur District in 2022 revealed that the dominant land use is agriculture or crop land (79.1 %), followed by Built-up land (Rural) (8 %), Waterbodies (7.4 %) (Table 61). The district also covers approximately 1798 hectares (0.5 %) of mangrove areas (Figure 89). Thanjavur District having the highest mangrove cover compared to other coastal districts in Tamil Nadu. Within Thanjavur District, important mangrove patches include Thamarankottai, Keelathottam, Manora Mangroves, Villunivayal, and Somanathanpattinam.

Table 61. Land use Land Cover Assessment of Thanjavur District.

S. No.	Land use Land Cover	Area (ha)	% of Total area
1	Built-up land (Urban)	9268	2.71
2	Built-up land (Rural)	27501	8.0
3	Vegetated/Open area	4055	1.2
4	Industrial/ Mining area	282	0.1
5	Forest	126	0.04
6	Lagoon, Creeks, Mud Flats, Swamp	2313	0.68
7	Saltpans	356	0.1
8	Waterbody	25198	7.4
9	Sandy Beaches	38	0.01
10	Wastelands	746	0.22
11	Agricultural land	270955	79.1
12	Mangroves	1798	0.5
TOTAL		342635	100.0

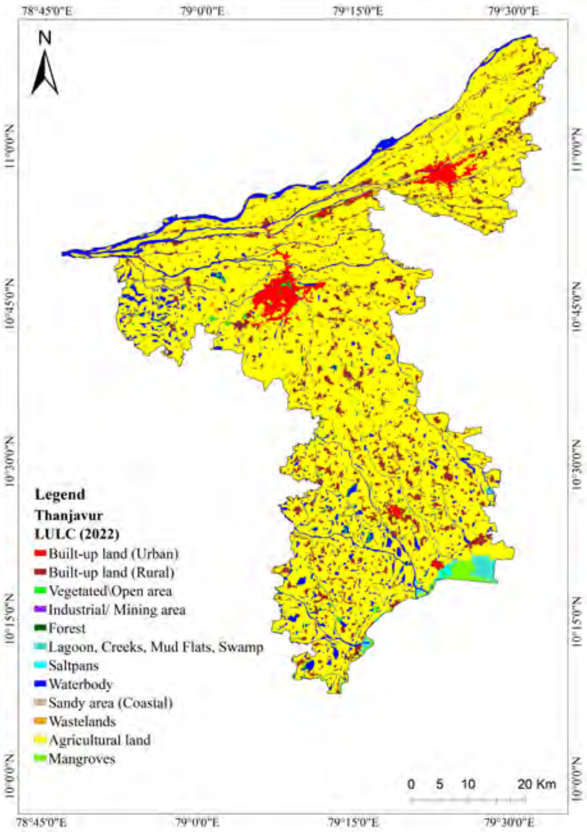


Figure 89 Land use and Land Cover (LULC) of Thanjavur District

4.9.2 Assessment of the Shoreline Change for Thanjavur District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), about 7.26 km of coastal length is under low erosion, while 17.22 km is under low accretion (Table 62). It is observed that Thambikottai Vadakadu, Thambikottai melakkadu, Thamarankottai are highly eroded (Table 64) (Figure 90). The erosion rate is 0.8 m/year, while the accretion rate is 1.2 m/year. The eroding hotspot villages were identified, and the length was calculated. The study revealed that about 44 ha of land loss and 78 ha of land gain were observed in the Tanjavur district area over a period of 30 years.

Table 62. Shoreline change assessment of Thanjavur District.

Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
Pattukottai	14.80	-	0.85	5.66	3.65	3.99	0.48	0.16
Sethubavachatram - 1	8.38	-	-	1.37	3.55	3.47	-	-
Sethubavachatram - 2	20.09	-	-	0.23	8.36	9.75	0.92	0.82
Total	43.27	-	0.85	7.26	15.56	17.22	1.40	0.98

HE - High Erosion,ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

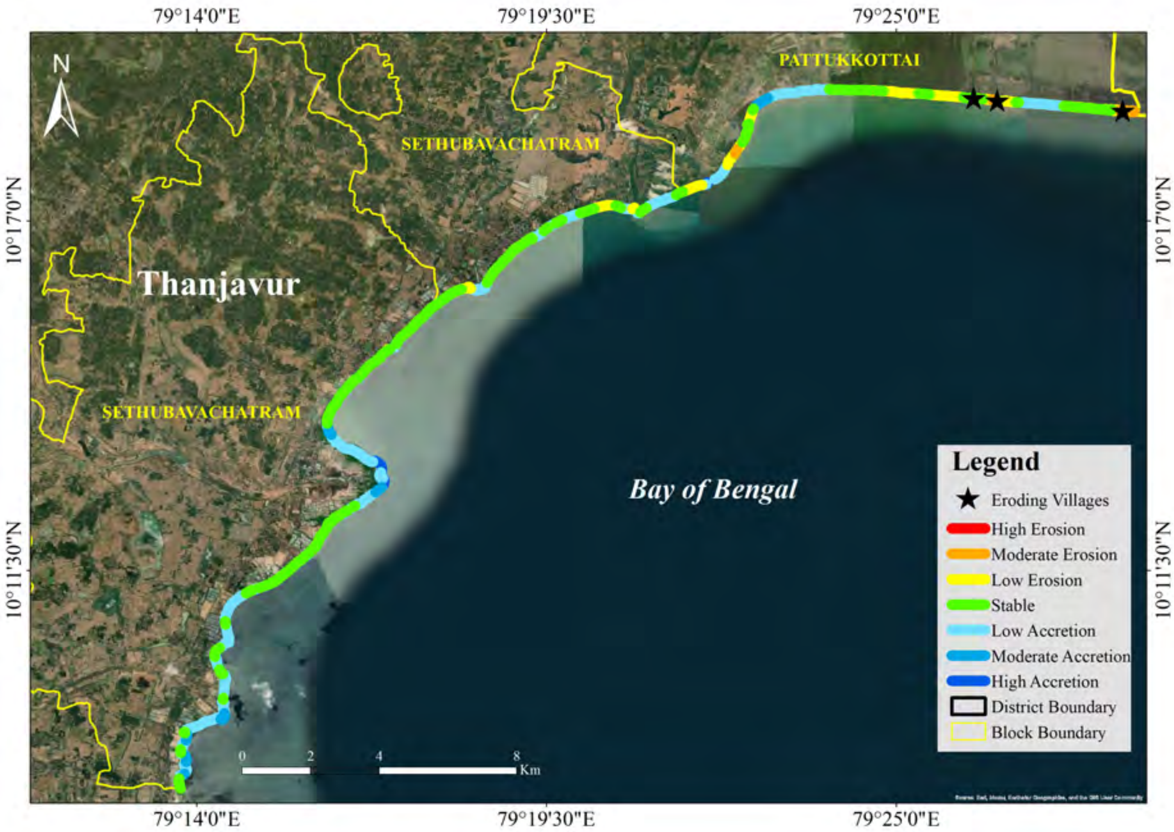


Figure 90 Shoreline Change map of Thanjavur District from 1992 - 2022

Table 63. Eroding hotspots of Thanjavur District.

S. No.	District Name	Block Name	Village Name	Length in Km
1	Thanjavur	Pattukkottai	Thambikkottai Vadakadu	1
2			Thambikkottai Melakkadu	0.48
3			Thamarankottai	0.91

4.9.3 SLR Projections and Coastal Inundation in Thanjavur District

The projection of the total trend of SLR for the Thanjavur coast based on the SSP2 3.5 scenario (Medium Projection) for the near century is estimated as an average of 19.9 cm (Figure 91). The coastal inundation due to the rise in sea level is projected to be about 1830 ha. The inundation effect is mostly on Agriculture land and Lagoon, Creeks, Mudflats and swamps (Figure 92).

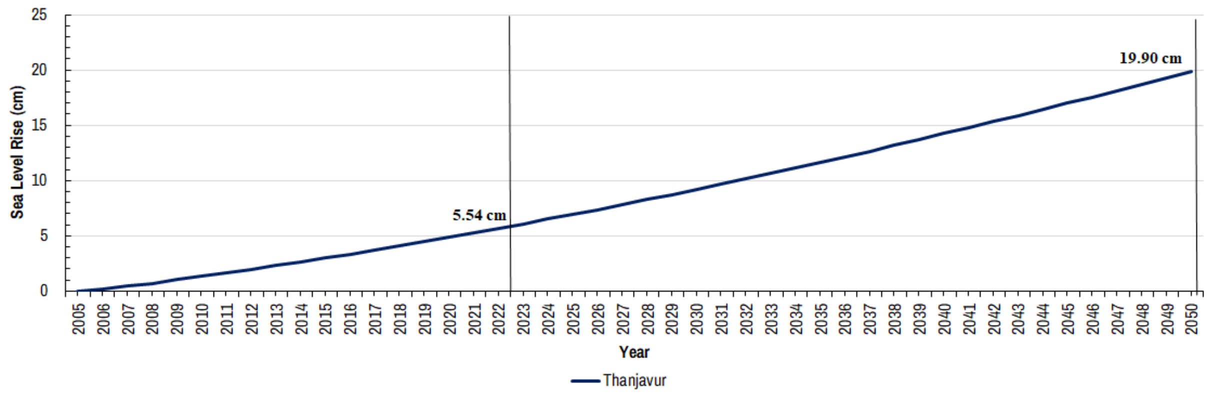


Figure 91 Projected SLR of Thanjavur District under SSP2- 4.5 (cm) for the Near Century

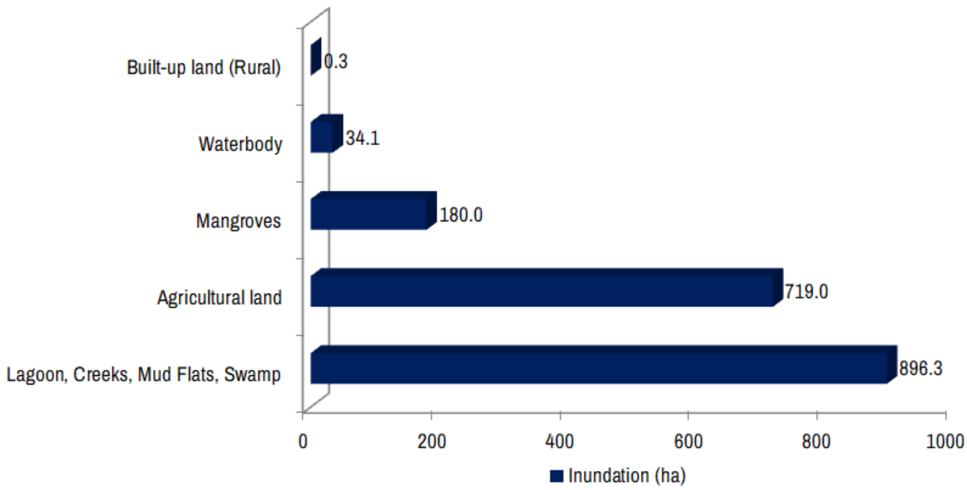


Figure 92 Impact of coastal inundation on land use land cover of Thanjavur District.

4.9.4 Coastal Risk Assessment of Thanjavur District

The coastline of Thanjavur is highly vulnerable to multiple hazards, with 15 km in the base period and 21.6 km in the projected period being particularly susceptible (Table 64). In terms of vulnerability and exposure, the Thanjavur coast is classified as high - very high (Figure 93). Thus, the risk for the coastline has increased both in the baseline and projected periods.

Table 64. Integrated Coastal Risk Assessment for Thanjavur District (km).

S. No.	Thanjavur	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	17	10.1	0.0	0.0	5.0	3.4
2	Low	0.6	0.5	1.8	11.6	8.9	7.7
3	Moderate	15.3	12.4	8.5	17.7	10.8	8.2
4	High	15.0	21.6	34.2	15.3	19.9	25.3
	Total	44.6	44.6	44.6	44.6	44.6	44.6

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

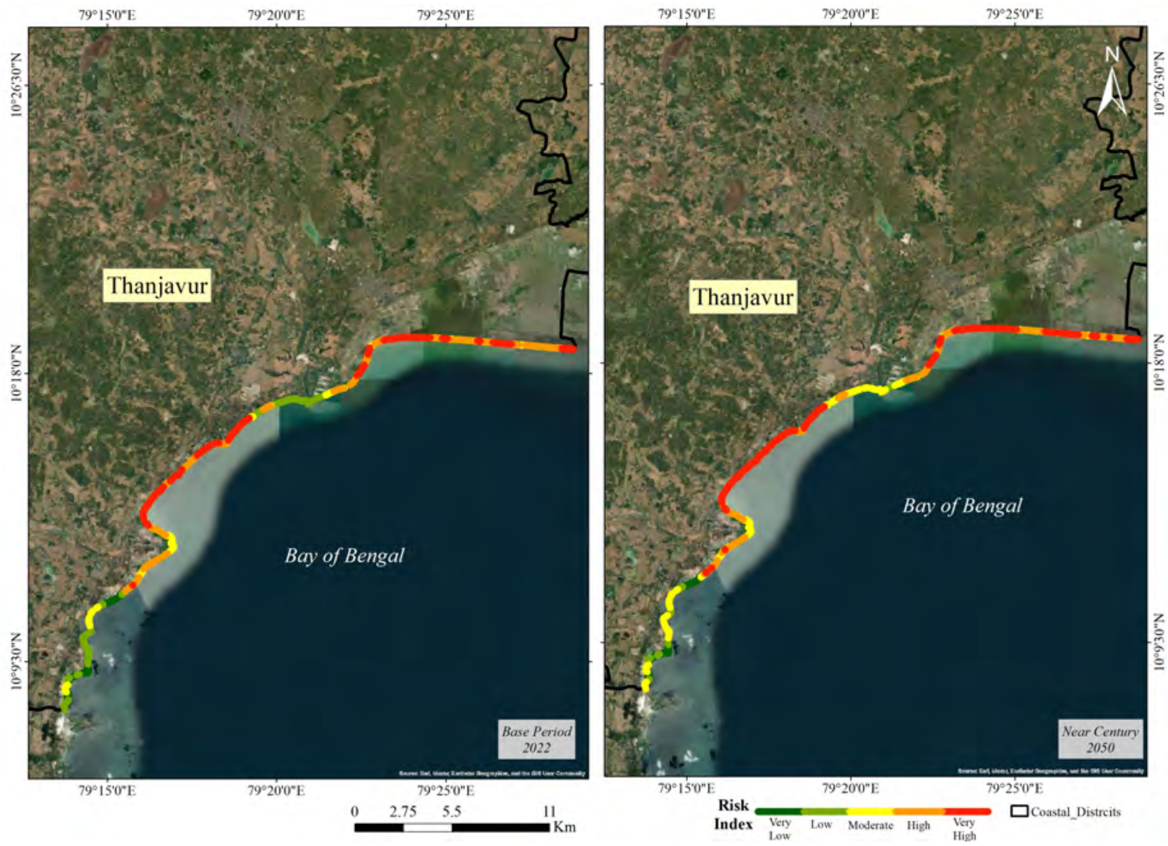


Figure 93 Coastal Risk Index map of Thanjavur District

4.10 Pudukkottai

The district lies between 78.25' to 79.15' of the Eastern Longitude and between 9.50' to 10.40' of the Northern Latitude (Figure 94). The district is part of Palk Bay and has two coastal blocks, Manamelkudi and Avudaiyar Koil, covering 42.8 km of coastal length covering 32 fishing villages. Agniyar, Ammliyar, South Vellar and GA Canal are the flowing water sources of the Pudukkottai district. According to the Tamil Nadu Fisheries Department in 2022, the district has a fisherman population of 11791 individuals.

The district is characterised by an undulating topography with residual hills in the northern, western and southern parts, whereas the eastern part of the district is a flat terrain consisting of alluvial plains. The elevation of the terrain of the western part of the area is about 125 m above MSL, whereas, towards the coast, it is about 1 m above MSL.

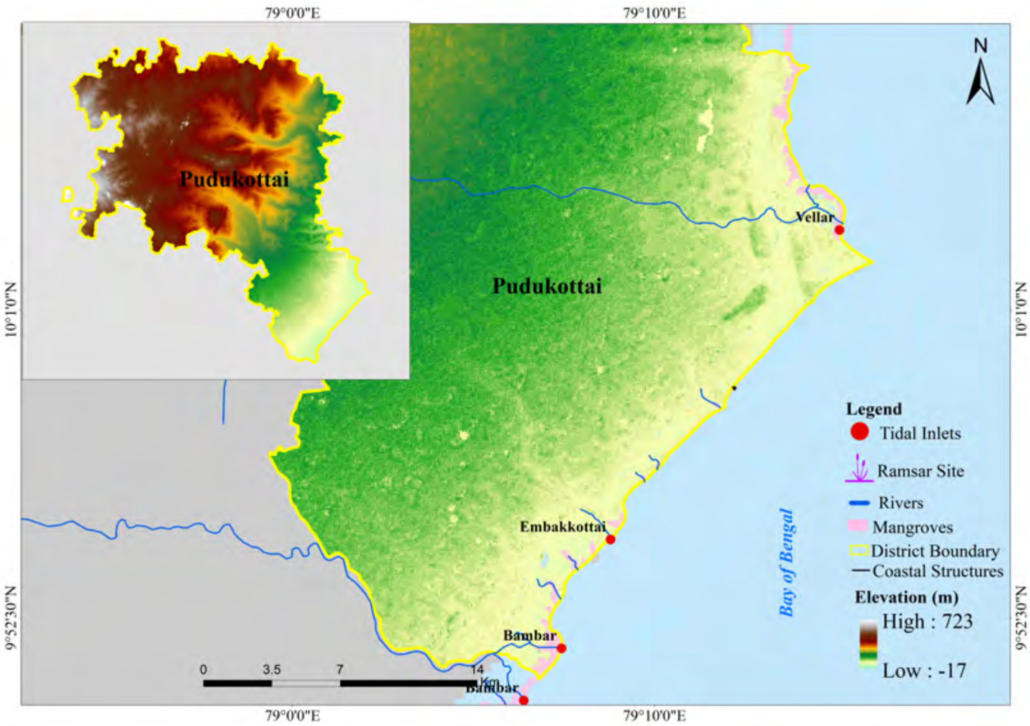


Figure 94 Coastal Profile map of Pudukkottai District

4.10.1 Land use Land Cover (LULC) of Pudukkottai District

The LULC assessment conducted for Pudukkottai District in 2022 revealed that the dominant land use is agriculture or crop land (74.5 %), followed by Waterbodies (13.9 %), Built-up land (Rural) (4 %) (Table 65). The district also covers approximately 396 hectares (0.1 %) of 9mangrove areas (Figure 95).

Table 65. Land use Land Cover Assessment of Pudukkottai District.

S. No.	Land use Land Cover	Area (ha)	% of Total area
1	Built-up land (Urban)	1425	0.3
2	Built-up land (Rural)	18670	4.0
3	Vegetated/Open area	9280	2.0
4	Industrial/ Mining area	1778	0.4
5	Forest	12041	2.6
6	Lagoon, Creeks, Mud Flats, Swamp	422	0.1
7	Saltpans	305	0.1
8	Waterbody	64814	13.9
9	Sandy Beaches	36	0.01
10	Wastelands	9615	2.1
11	Agricultural land	347327	74.5
12	Mangroves	396	0.1
TOTAL		466110	100.0

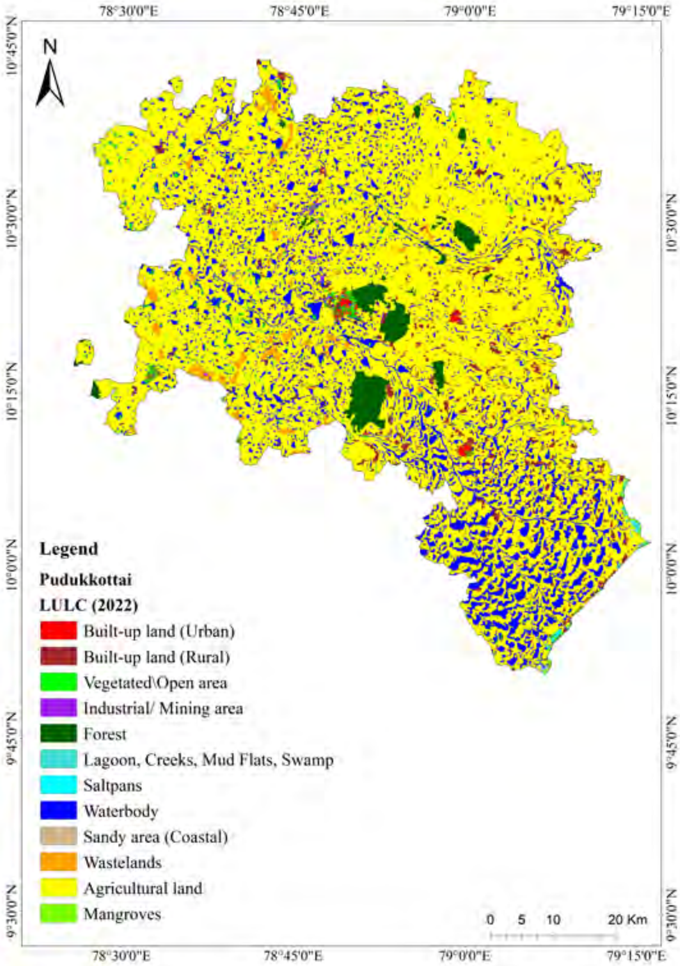


Figure 95 Land use and Land Cover (LULC) of Pudukkottai District

4.10.2 Assessment of the Shoreline Change for Pudukkottai District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), about 14.55 km of coastal length is under low erosion, while 7.13 km is under low accretion (Table 66). The erosion rate is 0.7 m/year, while the accretion rate is 0.8 m/year. The eroding hotspot village was identified, and the length was calculated. It is observed that Melasthanam are highly eroded (Figure 96). The study revealed that about 38 ha of land loss and 20 ha of land gain were observed in the Pudukkottai district area over a period of 30 years.

Table 66. Shoreline change assessment of Pudukkottai District.

S. No.	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Manamelkudi	32.21	0.22	-	8.27	16.52	7.04	0.16	-
2	Avudaiyarkoil	11.34	0.06	0.05	6.28	4.87	0.08	-	-
3	Total	43.55	0.28	0.05	14.55	21.38	7.13	0.16	-

HE - High Erosion,ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

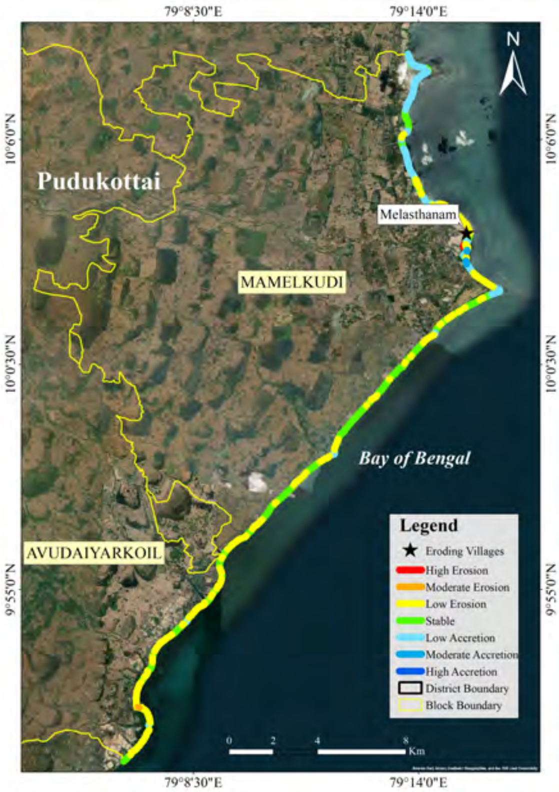


Figure 96 Shoreline Change map of Pudukkottai District from 1992 - 2022

Table 67. Eroding hotspots of Pudukkottai District.

S. No.	District Name	Block Name	Village Name	Length in Km
1	Pudukkottai	Mamelkudi	Melasthanam	1.6

4.10.3 SLR Projections and Coastal Inundation in Pudukkottai District

The projection of the total trend of SLR for the Pudukkottai coast based on the SSP2 4.5 scenario (Medium Projection) for the near century is estimated as an average of 20 cm (Figure 97). The coastal inundation due to the rise in sea level is projected to be about 17 ha. The inundation effect is mostly on lagoons, creeks, mudflats, swamps, mangroves, and agricultural land (Figure 98).

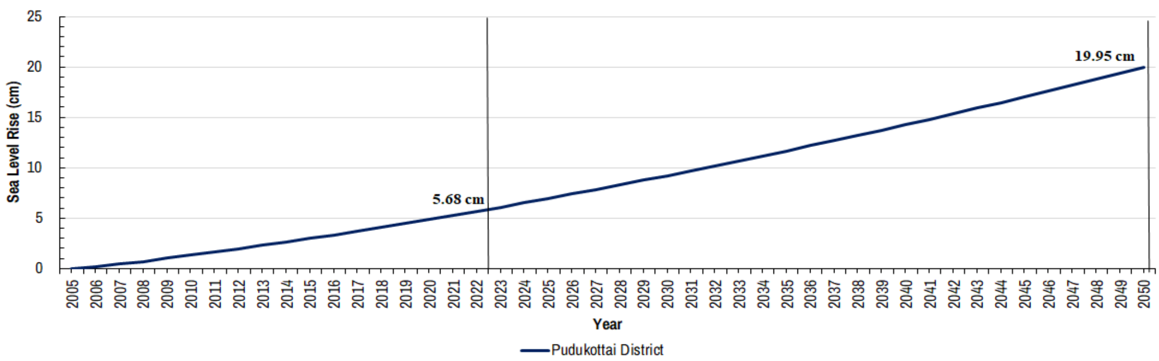


Figure 97 Projected SLR of Pudukkottai District under SSP2- 4.5 (cm) for the Near Century

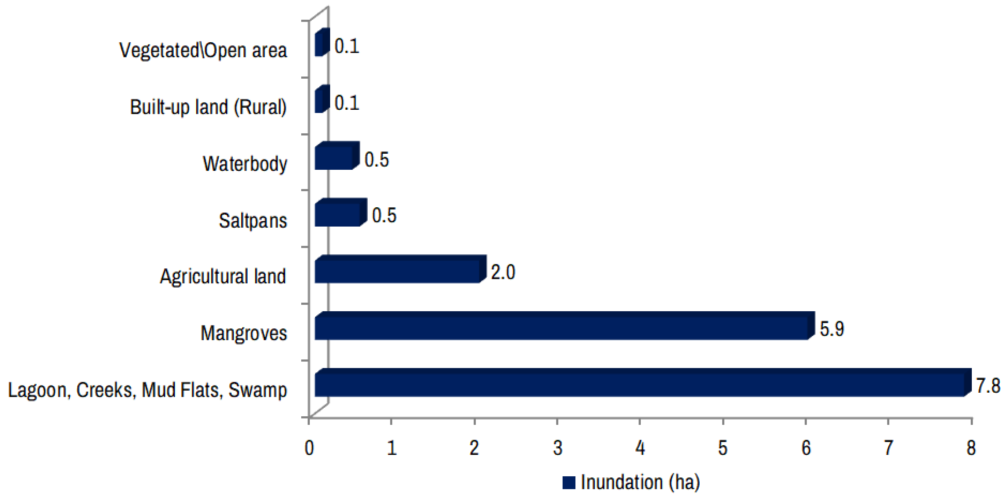


Figure 98 Impact of coastal inundation on land use land cover of Pudukkottai District.

4.10.4 Coastal Risk Assessment of Pudukkottai District

The coastline of Pudukkottai shows a low vulnerability to multiple hazards, with 5 km in the base period and 13.1 km in the projected period being particularly susceptible (Table 68). In terms of vulnerability, the Pudukkottai coast is classified as very high, while the exposure is categorized as moderate (Figure 99). As a result, the risk for the coastline remains constant in both the baseline and projected periods.

Table 68. Integrated Coastal Risk Assessment for Pudukkottai District (km).

S. No.	Pudukkottai	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	12.3	9.1	0.3	3.5	10.9	8.0
2	Low	13.0	10.8	3.0	11.4	2.5	2.1
3	Moderate	14.2	11.5	6.1	6.2	14.5	11.8
4	High – Very High	5.0	13.1	35.2	23.4	16.7	22.7
	Total	44.6	44.6	44.6	44.6	44.6	44.6

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

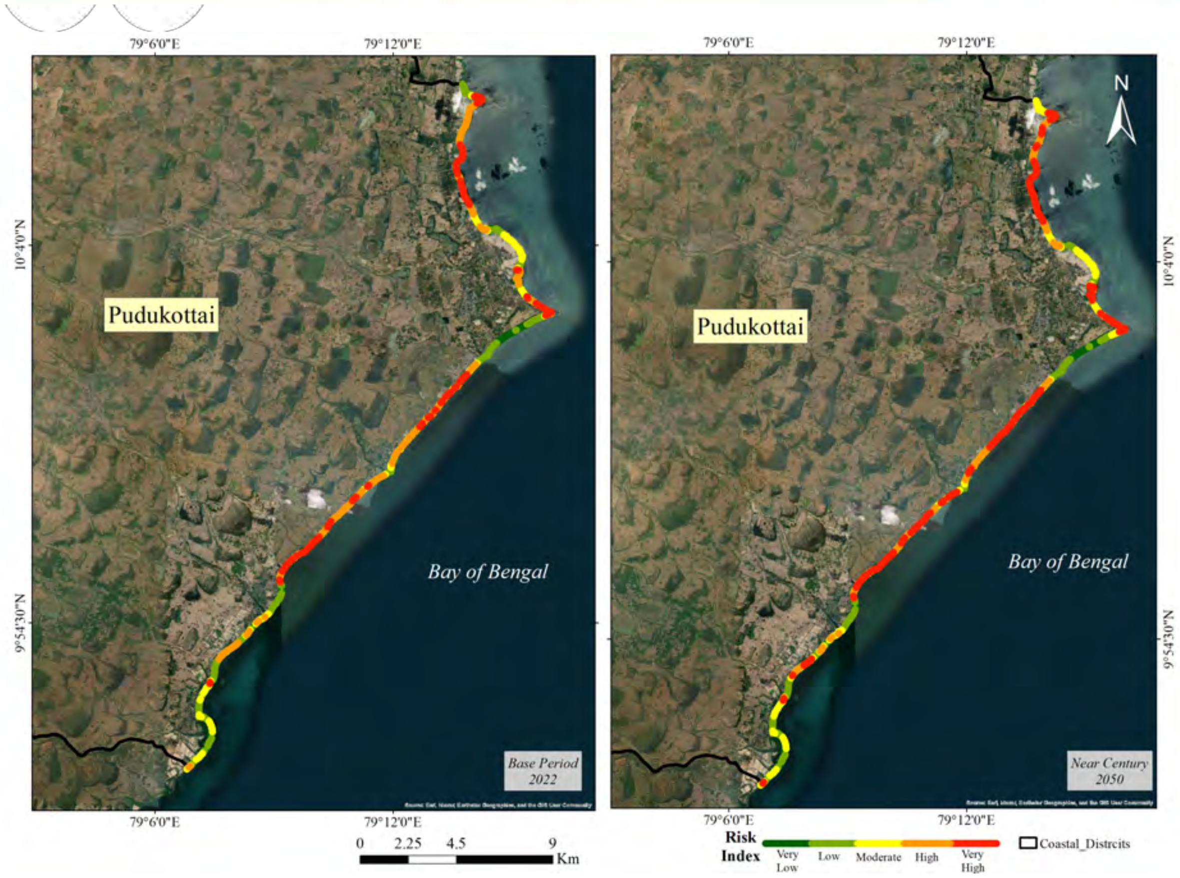


Figure 99 Coastal Risk Index map of Pudukottai District

4.11 Ramanathapuram

The district extends between 9° 05′ to 9° 50′ of the northern latitudes and 78° 10′ to 79° 27′ of the eastern longitudes (Figure 100). The district has the longest coastal length of 237 km, enjoying ecosystem services from the Gulf of Mannar in the south and Palk Strait in the north. In 2022, the Indian government considered the Gulf of Mannar Marine Biosphere Reserve, Chitrangidi, and Kanjirankulam Bird Sanctuary as Ramsar sites. There are about 180 marine fishing villages contributing 33% of marine fish landings to the state. According to the Tamil Nadu Fisheries Department in 2022, the district has a fisherman population of 83032 individuals.

Gulf of Mannar is the ecologically richest area extending between 8° 35' to 9° 25' of the northern latitudes and 78° 08' to 79° 30' of the eastern longitudes, including 21 islands and covering an area of 10500 sq. km. Oliver Ridley and Dugong are well conserved within the marine biosphere. Sand dune beaches are predominant along the coast of the Gulf of Mannar.

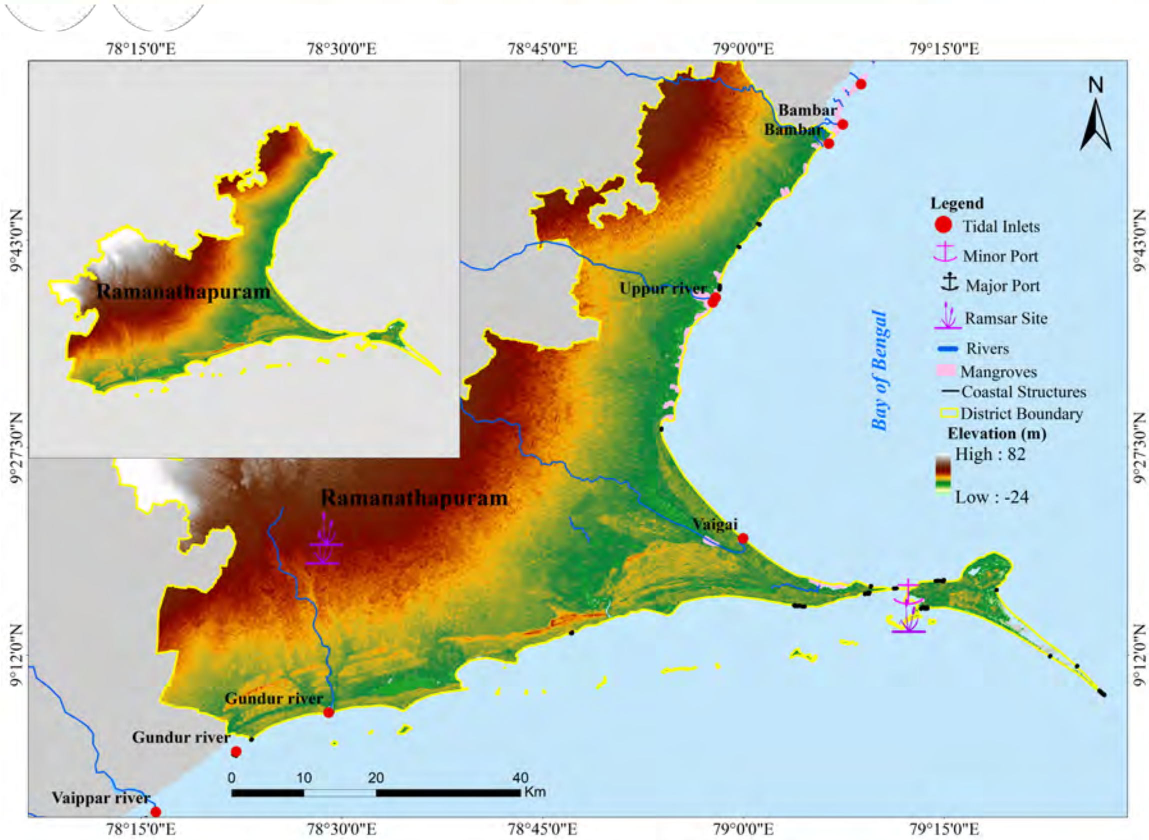


Figure 100 Coastal Profile map of Ramanathapuram District.

The coastal geomorphology of Ramanathapuram district in Tamil Nadu features sandy beaches, tidal flats, and dune formations. The district sandy beaches with gentle slopes and fine-grained sand, attracting tourists. Extensive tidal flats are present, submerged during high tide and exposed during low tide, formed by sediment deposition from rivers and ocean currents. Dune formations, found along the coast and inland areas, act as natural barriers against erosion and provide habitats for various plant and animal species.

4.11.1 Land use Land Cover (LULC) of Ramanathapuram District

The LULC assessment conducted for Ramanathapuram District in 2022 revealed that the dominant land use is agriculture or crop land (76.3 %), followed by Waterbodies (11.8 %), Vegetated/Open area (3.6 %), and Built-up land (Rural) (3.4 %) (Figure 73). The district also covers approximately 672 hectares (0.1 %) of mangrove areas (Table 69).

Table 69. Land use Land Cover Assessment of Ramanathapuram District.

S. No.	Land use Land Cover	Area (ha)	% of Total area
1	Built-up land (Urban)	1122	0.3
2	Built-up land (Rural)	13825	3.4
3	Vegetated/Open area	14690	3.6
4	Industrial/ Mining area	993	0.2
5	Forest	1944	0.5
6	Lagoon, Creeks, Mud Flats, Swamp	7295	1.8
7	Saltpans	1365	0.3
8	Waterbody	48379	11.8
9	Sandy Beaches	3801	0.9
10	Wastelands	3497	0.9
11	Agricultural land	313451	76.3
12	Mangroves	672	0.2
TOTAL		411034	100.0

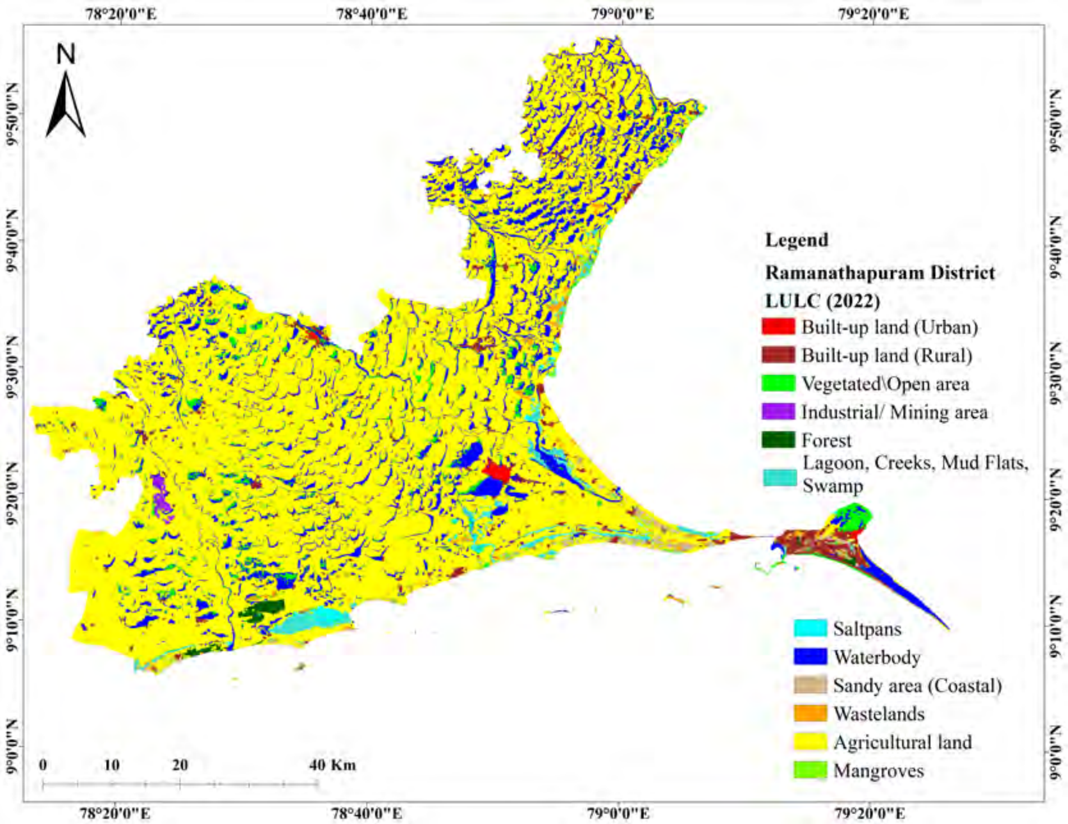


Figure 101 Land use and Land Cover (LULC) of Ramanathapuram District

4.11.2 Assessment of the Shoreline Change for Ramanathapuram District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), about 2.28 km of coastal length under high erosion, 4.61 km of coastline under moderate erosion, and 6.22 km under high accretion (Table 70). Out of 2.28 km of high erosion, 1.8 km of coast under Mandapam block is vulnerable to shoreline changes. The erosion rate is 1.2 m/year, while the accretion rate is 1.9 m/year. The eroding hotspot villages were identified, and the length was calculated. It is observed that Mandapam, Pamban, Rameshwaram, Erwadi, Valinokam, and Mokkaiyur are highly eroded (Table 71), while Pathanenthal, Pamban and Rameshwaram villages are observed with high accretion (Table 72) (Figure 102). The study revealed that about 558 ha of land loss and 194 ha of land gain were observed in the Ramanathapuram district area over a period of 30 years.

Table 70. Shoreline change assessment of Ramanathapuram District.

S. No.	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Thiruvadanai	25.13	-	-	5.03	18.22	1.71	0.17	-
2	R.S.Mangalam	19.02	-	-	5.24	10.18	2.84	0.59	0.17
3	Ramanathapuram	17.19	0.17	0.26	9.40	6.17	1.19	-	-
4	Mandapam - 1	64.26	0.31	1.48	15.15	42.72	3.69	0.91	-
5	Mandapam - 2	79.41	1.80	1.50	29.15	25.31	16.05	0.78	4.82
6	Thirupullani	23.60	-	-	10.96	9.26	3.26	0.12	-
7	Kadaladi	47.08	-	1.37	21.23	19.19	3.63	0.43	1.23
	Total	275.71	2.28	4.61	96.18	131.06	32.37	3.00	6.22

HE - High Erosion, ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

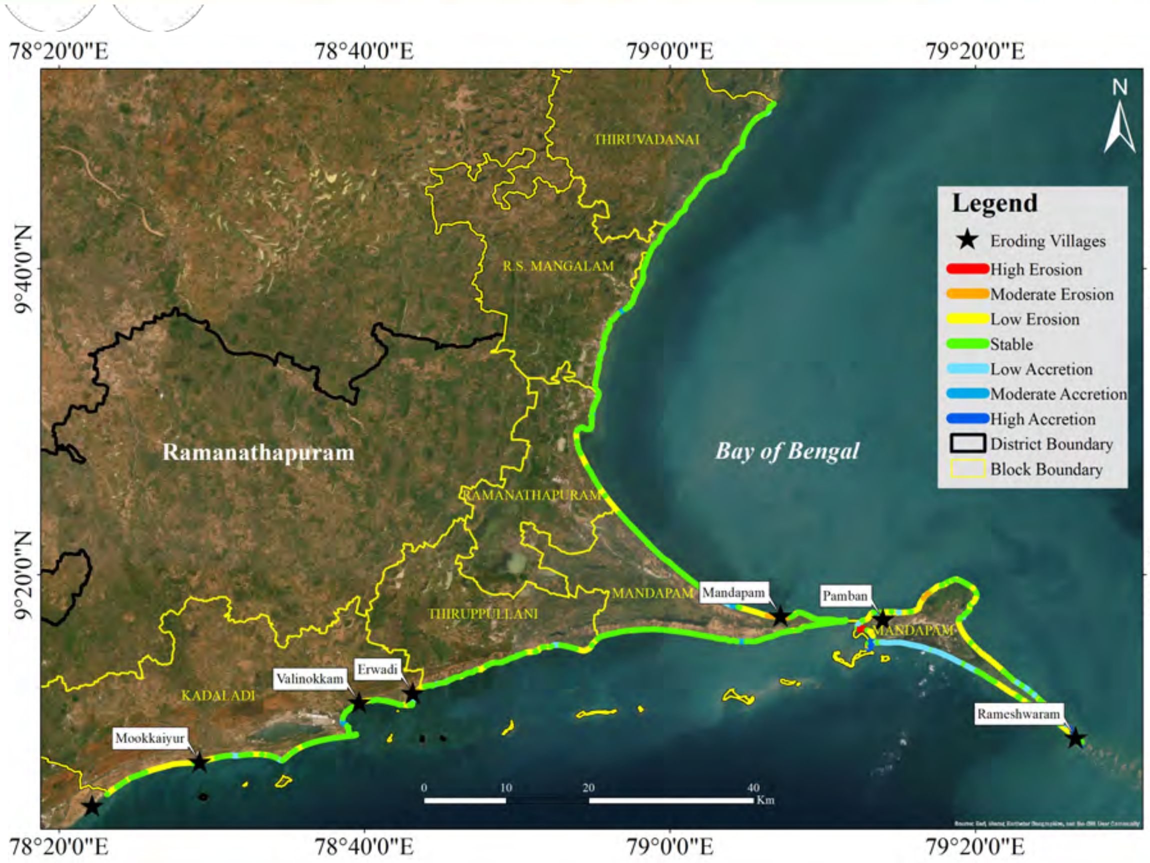


Figure 102 Shoreline Change map of Ramanathapuram District from 1992 - 2022

Table 71. Eroding hotspots of Ramanathapuram District.

S. No.	District Name	Block Name	Village Name	Length in Km
1	Ramanathapuram	Mandapam	Mandapam	3.79
2		Mandapam - II	Pamban	3.81
3			Rameshwaram	4.7
4		Kadaladi	Erwadi	0.12
5			Valinokkam	0.5
			Mookkaiyur	1.12

Table 72. Accretion-dominant villages in Ramanathapuram District.

S. No.	District Name	Block Name	Village Name	Length in Km
1	Ramanathapuram	Ramanathapuram	Pathanenthal	1.09
2		Mandapam	Pamban	3.15
3			Rameshwaram	4.99

4.11.3 SLR Projections and Coastal Inundation in Ramanathapuram District

The projection of the total trend of SLR for the Ramanathapuram coast based on the SSP2 4.5 scenario (Medium Projection) for the near century is estimated as an average of 20 cm (Figure 103). The coastal inundation due to the rise in sea level is projected to be about 1799 ha. The inundation effect is mostly on lagoons, creeks, mudflats, swamps, and saltpans (Figure 104).

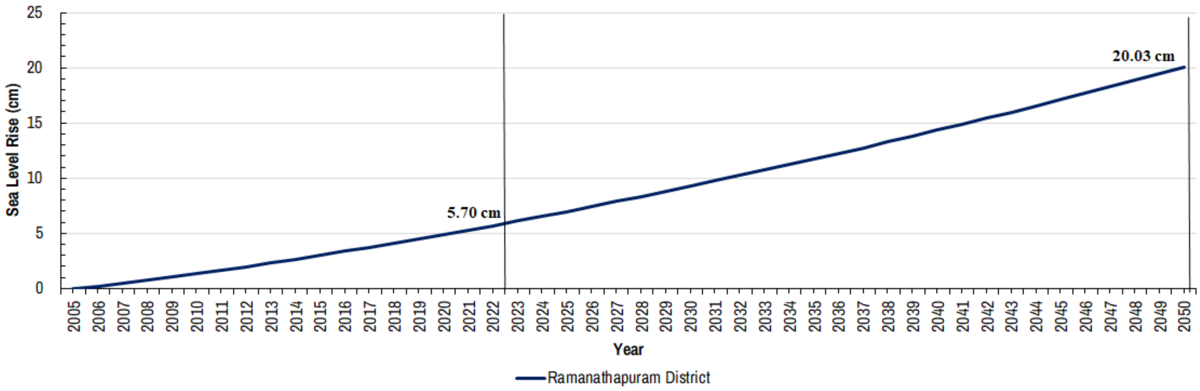


Figure 103 Projected SLR of Ramanathapuram District under SSP2- 4.5 (cm) for the Near Century

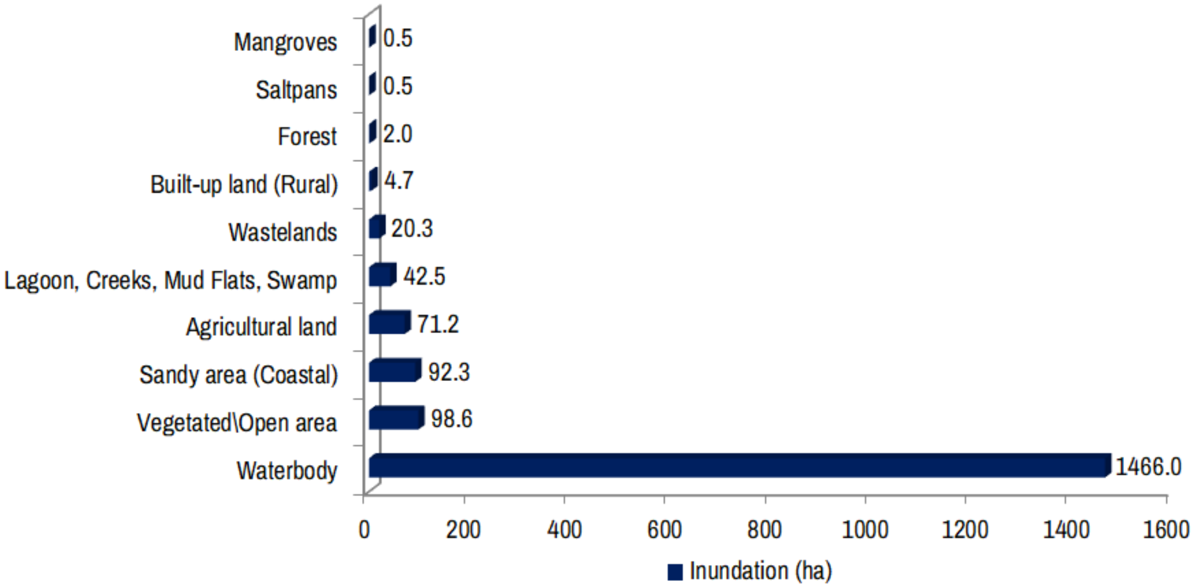


Figure 104 Impact of coastal inundation on land use land cover of Ramanathapuram District.

4.11.4 Coastal Risk Assessment of Ramanathapuram District

The coastline of Ramanathapuram is very low and vulnerable to multiple hazards, with 146.1 km in the base period and 169.1 km in the projected period being particularly susceptible (Table 73). In terms of vulnerability and exposure, the Ramanathapuram coast is classified as very high and very low (Figure

105). Thus, the risk for the coastline has remained the same both in the baseline and projected periods.

Table 73. Integrated Coastal Risk Assessment for Ramanathapuram District (km).

S. No.	Ramanathapuram	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	0.0	0.0	4.7	38.2	75.4	55.8
2	Low	99.0	82.1	15.6	48.0	36.8	27.1
3	Moderate	32.9	26.7	24.9	51.8	36.9	32.7
4	High – Very High	146.1	169.1	232.8	140.0	128.8	162.3
	Total	277.9	277.9	277.9	277.9	277.9	277.9

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

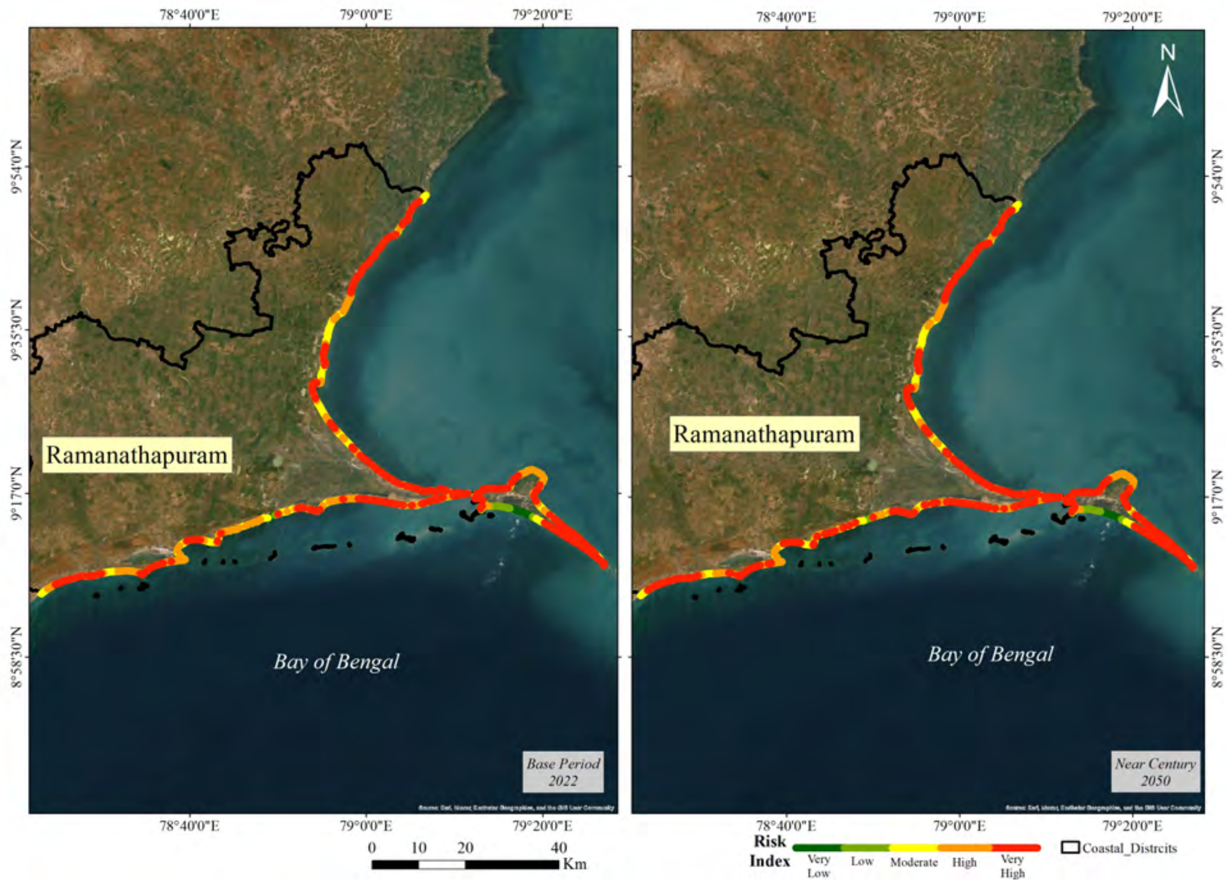


Figure 105 Coastal Risk Index map of Ramanathapuram District

4.12 Thoothukudi

The district is famously known as "Pearl City" owing to its pearl cultivation prevailing from the ancient past of maritime trade. V.O. Chidambaranar Port is one of the 12 major ports in Tamil Nadu. The district extends between 8°19' to 90 20' of the Northern latitudes and 77° 40' E to 78° 10' of the Eastern longitudes and covers (Figure 106). Thoothukudi is part of the Gulf of Mannar and has eight blocks along the coast – Vilathikulam, Ottaipidaram, Thoothukudi, Srivaikundam, Alwarthirunagari, Thituchendur, Udankudi, and Sattankulam, along the coastal length of 164 km. These people enjoy ecosystem services from the Gulf of Mannar. Salt production is dominant along the coast, contributing 70 % of the production to the state and 30 % to the country. There are 23 marine fishing villages contributing 10% of marine fish landings to the state. According to the Tamil Nadu Fisheries Department in 2022, the district has a fisherman population of 32873 individuals.

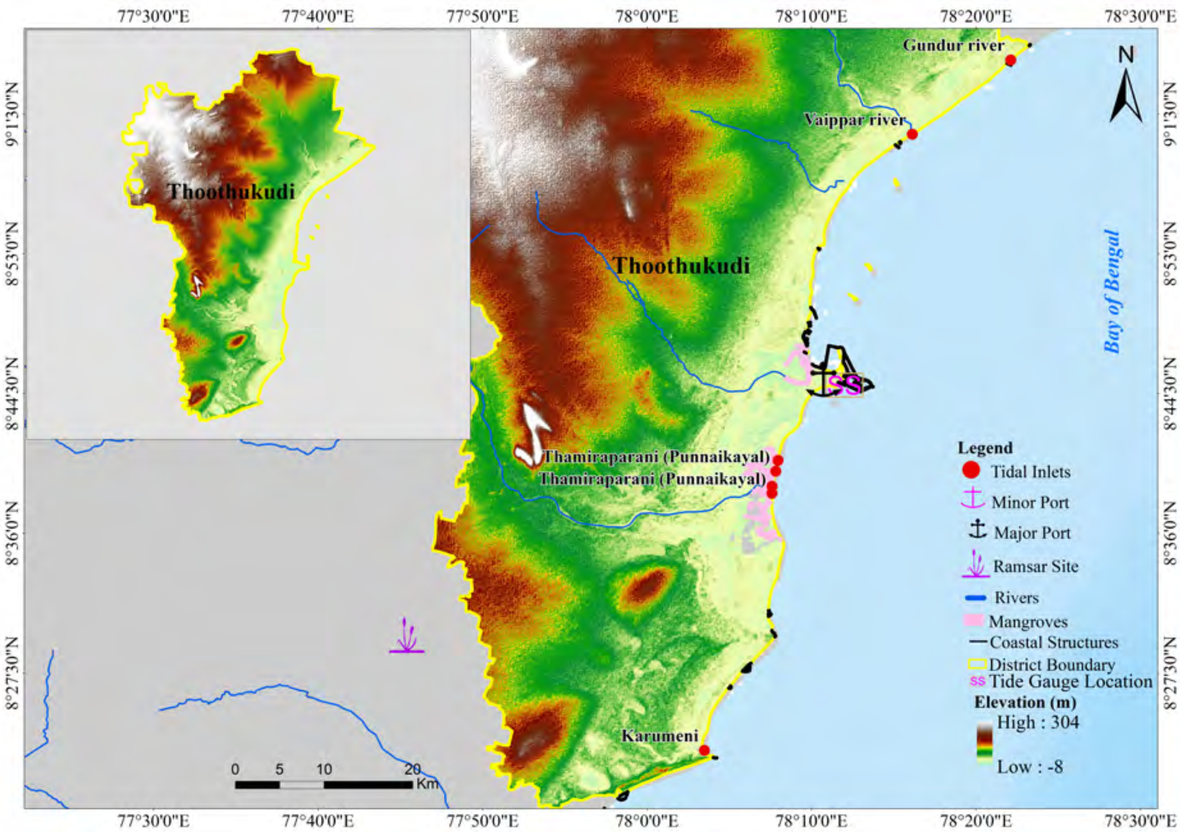


Figure 106 Coastal Profile map of Thoothukudi District

The Thoothukudi district shows various prominent geomorphic units, including fluvial, marine, fluvio-marine, aeolian, and erosional landforms. The coast in the district features several red sandy tracts formed by sand dunes, known locally as the Teri sand complex. These Teri sands extend about 6 to 8 km from the coast and include important areas such as Adaippanvilai Teri, Kudiraimozhi Teri, and Vaippar-Vembar Teri, which have elevations ranging from 15 to 62 m above MSL (CGWB, 2009).

4.12.1 Land use Land Cover (LULC) of Thoothukudi District

The LULC assessment conducted for Thoothukudi District in 2022 revealed that the dominant land use is agriculture or crop land (80.8 %), followed by Wastelands (3.5 %), and Waterbodies (3.2 %) (Table 74). The district also covers approximately 616 hectares (0.1 %) of mangrove areas (Figure 107).

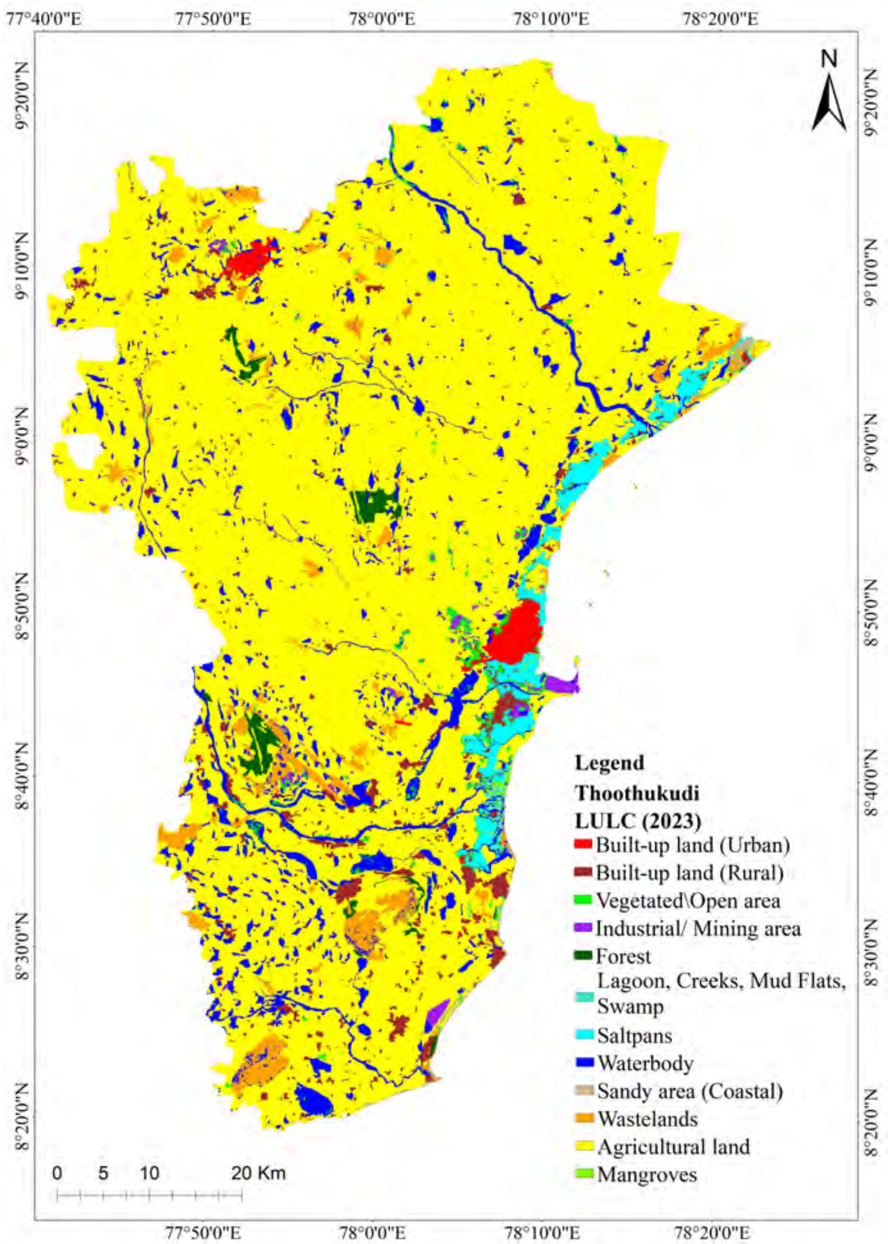


Figure 107 Land use and Land Cover (LULC) of Thoothukudi District

Table 74. Land use Land Cover Assessment of Thoothukudi District.

S. No.	Land use Land Cover	Area (ha)	% of Total area
1	Built-up land (Urban)	4116	0.9
2	Built-up land (Rural)	15201	3.2
3	Vegetated/Open area	5307	1.1
4	Industrial/ Mining area	2486	0.5
5	Forest	3867	0.8
6	Lagoon, Creeks, Mud Flats, Swamp	974	0.2
7	Saltpans	8823	1.9
8	Waterbody	32199	6.8
9	Sandy Beaches	1194	0.3
10	Wastelands	16649	3.5
11	Agricultural land	383792	80.8
12	Mangroves	616	0.1
TOTAL		475224	100.0

4.12.2 Assessment of the Shoreline Change for Thoothukudi District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), about 1.98 km of coastal length under high erosion, 4.48 km of coastline under moderate erosion, 21.63 km of coastline under low erosion, while 8.54 km under high accretion (Table 75). The coastal blocks vulnerable to erosion are Vilathikulam, Srivaikundam, and Alwarthirunagiri are vulnerable to shoreline changes. The erosion rate is 2.0 m/year, while the accretion rate is 3.0 m/year. The eroding hotspot villages were identified, and the length was calculated. It is observed that Vembar, Vaippar, Pazhayakayal, mukkani, and Punnaikayal are highly eroded (Table 76), while Mullakkadu, kayalpattinam, udankudi villages observed with high accretion (Table 77) (Figure 108). The study revealed that about 167 ha of land loss and 286 ha of land gain were observed in the Thoothukudi district area over a period of 30 years.

Table 75. Shoreline change assessment of Thoothukudi District.

S. No.	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Vilathikulam	23.70	0.27	1.69	8.54	7.69	5.50	-	-
2	Ottapidaram	15.17	-	-	2.80	9.24	2.46	0.63	0.04
3	Thoothukudi	24.61	0.46	0.88	5.56	6.68	4.15	2.27	4.61
4	Srivaikundam	7.94	-	1.48	1.81	0.70	0.98	0.59	2.37
5	Alwarthirunagari	12.75	1.24	0.42	0.85	0.71	5.77	3.48	0.28
6	Thiruchendur	13.52	-	-	1.66	2.49	8.58	0.70	0.10
7	Udankudi	16.94	-	-	0.41	1.20	9.86	4.33	1.14
8	Sattankulam	4.23	-	-	-	-	4.22	0.01	0.01
	Total	118.88	1.98	4.48	21.63	28.70	41.52	12.02	8.54

HE - High Erosion, ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

Table 76. Eroding hotspots of Thoothukudi District.

S. No.	District Name	Block Name	Village Name	Length in Km
1	Thoothukudi	Vilathikulam	Vembar	1.27
2			Vaippar	1.73
3		Srivaikundam	Pazhayakayal	2.05
4			Mukkani	0.5
		Alwarthirunagiri	Punnaikayal	1.83

Table 77. Accretion dominant villages in Thoothukudi District.

S. No.	District Name	Block Name	Village Name	Length in Km
1	Thoothukudi	Thoothukudi	Meelavittan	1.19
2			Mullakkadu	4.26
3		Srivaikundam	Pazhayakayal	2.89
4		Alwarthirunagari	Punnaikayal	1.35
5			Kayalpattinam	3.84
6		Udangudi	Udankudi	3.53
7			Kulasekarapattanam	1.08
8			Manappadu	1.25

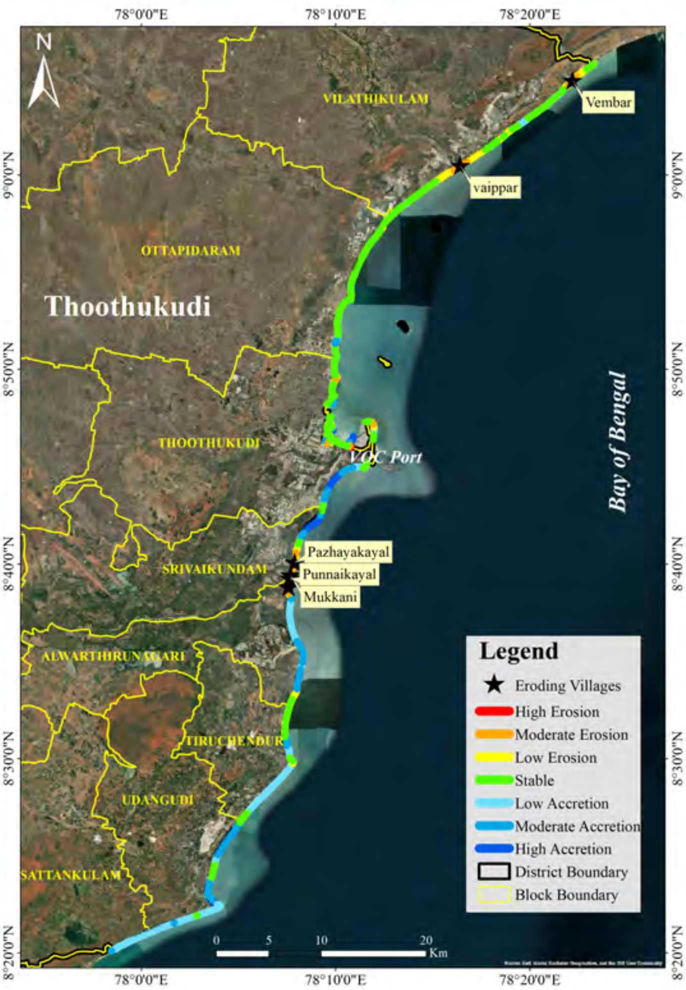


Figure 108 Shoreline Change map of Thoothukudi District from 1992 - 2022

4.12.3 SLR Projections and Coastal Inundation in Thoothukudi District

The projection of the total trend of SLR for the Thoothukudi coast based on the SSP2 4.5 scenario (Medium Projection) for the near century is estimated as an average of 20.1 cm (Figure 109). The coastal inundation due to the rise in sea level is projected to be about 1490 ha (Figure 110).

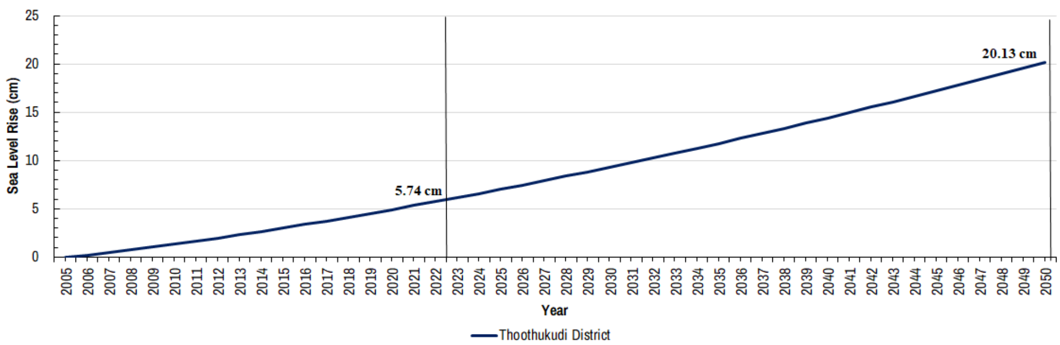


Figure 109 Projected SLR of Thoothukudi District under SSP2- 4.5 (cm) for the Near Century

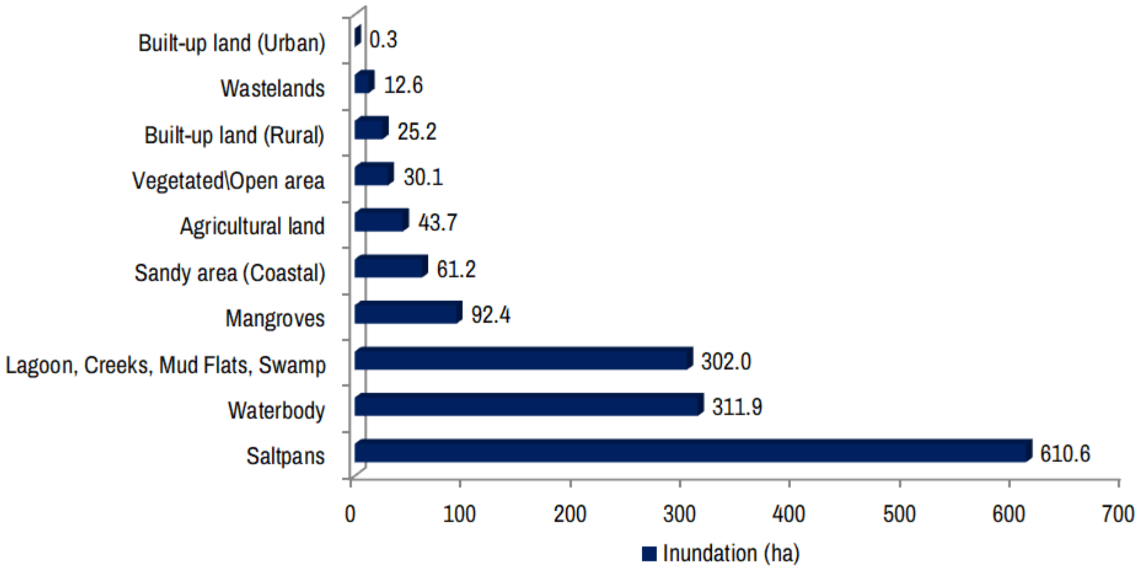


Figure 110 Impact of coastal inundation on land use land cover of Thoothukudi District.

4.12.4 Coastal Risk Assessment of Thoothukudi District

The coastline of Thoothukudi is moderately vulnerable to multiple hazards, with 56.2 km in the baseperiod and 71.6 km in the projected period being particularly susceptible (Table 78). In terms of vulnerability and exposure, the Thoothukudi coast is classified as high and very low (Figure 111). As a result, the risk for the coastline has increased both in the baseline and projected periods.

Table 78. Integrated Coastal Risk Assessment for Thoothukudi District (km).

S. No.	Thoothukudi	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	8.3	6.2	1.8	10.9	12.3	8.2
2	Low	18.0	14.9	13.4	31.6	34.5	15.1
3	Moderate	53.5	43.3	13.1	23.9	32.7	39.8
4	High – Very High	56.2	71.6	107.8	69.5	56.6	72.9
	Total	136.0	136.0	136.0	136.0	136.0	136.0

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

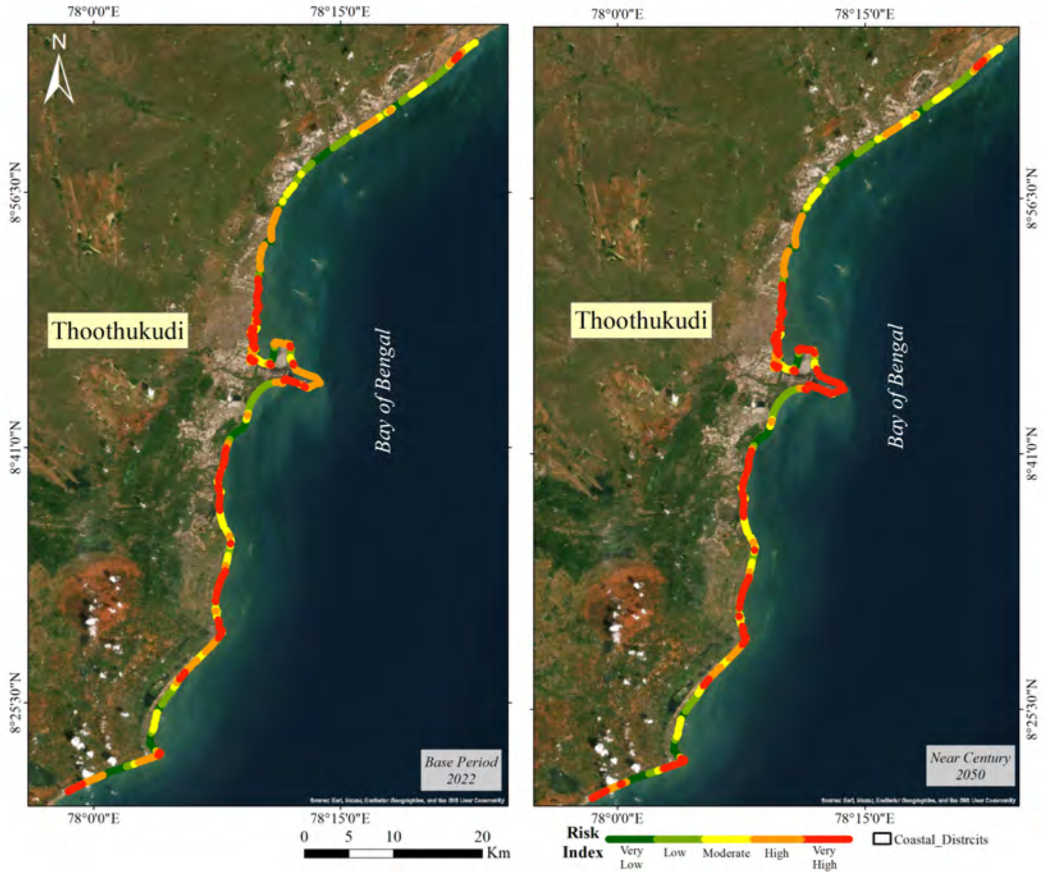


Figure 111 Coastal Risk Index map of Thoothukudi District

4.13 Tirunelveli

The district extends between 8°14′ to 9° 07′ of the northern latitudes and 77° 17′ E and 77° 97′ of the eastern longitudes (Figure 112). The district is part of the Gulf of Mannar and has two coastal blocks, Radhapuram and Valliyoor, covering 49 km of coastal length. Koothankulam Bird Sanctuary in the Nanguneri block is recognized as a Ramsar site in 2022. Koodankulam Nuclear Power plant, located at the coast, generates 1000 MW. According to the Tamil Nadu Fisheries Department in 2022, the district has a fisherman population of 11449 individuals.

Along the coast of Tirunelveli, a range of coastal geomorphologic features can commonly be observed, including beaches, beach ridges, a cliffed coast, sand dunes, beach terraces, spits, caspates, salt marshes, and Teri sands. Towards the southern region of Tiruchendur, the coastline is characterized by a narrow beach. Beyond this beach, there is an extension of a coastal ridge stretching from Manapadu to Kudangulam, atop which sand dunes and beach terraces have formed. Additionally, the coast from Periyatalai to Puvari displays exposed quaternary sandstones, forming a wave cut platform (CRZI-TN).

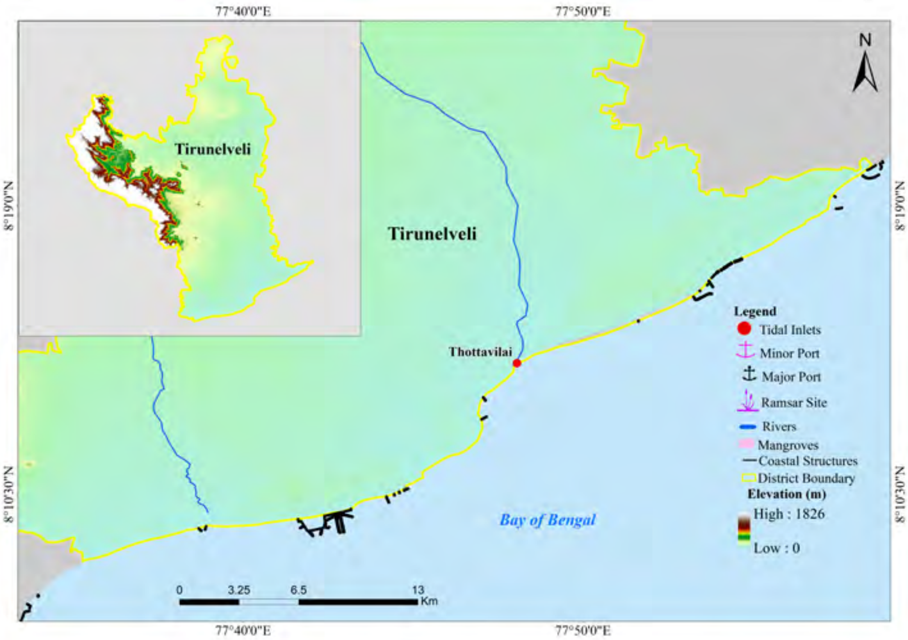


Figure 112 Coastal Profile map of Tirunelveli District

4.13.1 Land use Land Cover (LULC) of Tirunelveli District

The LULC assessment conducted for Tirunelveli District in 2022 (Figure 113) revealed that the dominant land use is agriculture or crop land (55.6 %), followed by Forest (21.9 %), Waterbodies (8.5 %), Wastelands (6.7 %), and Built-up land (Rural) (3.6 %) (Table 79).

Table 79. Land use Land Cover Assessment of Tirunelveli District.

S. No.	Land use Land Cover	Area (ha)	% of Total area
1	Built-up land (Urban)	7154	1.9
2	Built-up land (Rural)	13952	3.6
3	Vegetated/Open area	4227	1.1
4	Industrial/ Mining area	2201	0.6
5	Forest	84123	21.9
6	Lagoon, Creeks, Mud Flats, Swamp	56	0.01
7	Saltpans	2	0.001
8	Waterbody	32692	8.5
9	Sandy Beaches	323	0.1
10	Wastelands	25704	6.7
11	Agricultural land	213731	55.6
	Total	384166	100.0

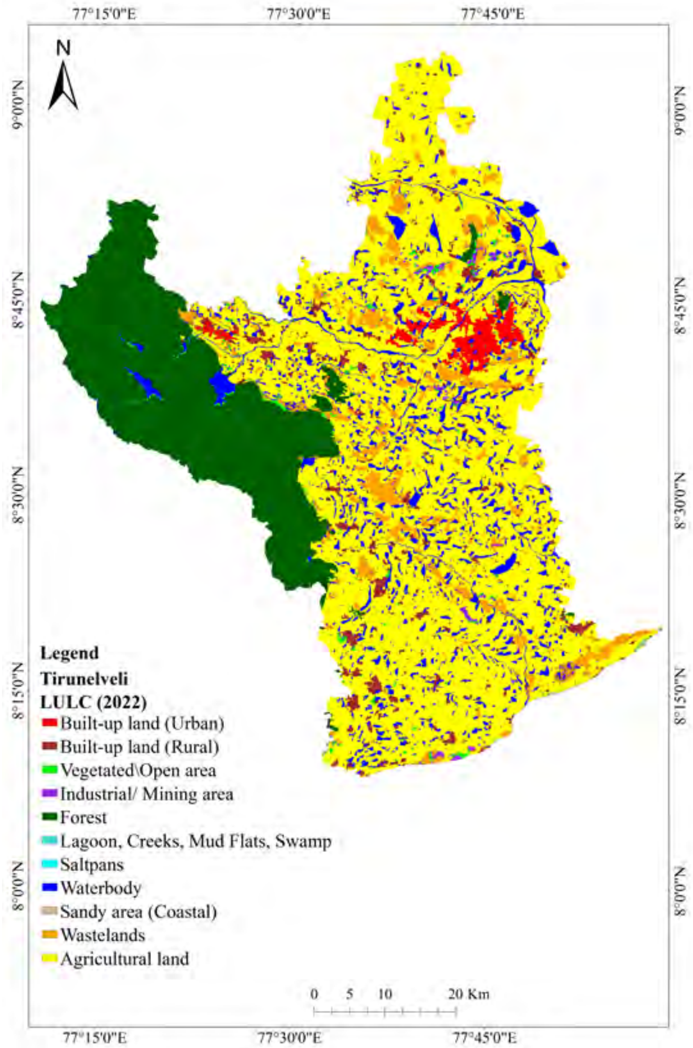


Figure 113 Land use and Land Cover (LULC) of Tirunelveli District

4.13.2 Assessment of the Shoreline Change for Tirunelveli District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), about 6.04 km of coastline was under low erosion, while 3.58 km was under high accretion (Table 80). The erosion rate is 0.5 m/year, while the accretion rate is 1.7 m/year. It is observed that Kuttam village has high accretion (Table 81) (Figure 114). The study revealed that about 38 ha of land loss and 173 ha of land gain were observed in the Tirunelveli district area over a period of 30 years.

Table 80. Shoreline change assessment of Tirunelveli District.

S. No.	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Radhapuram	42.70	-	-	6.04	18.70	12.40	1.97	3.58
2	Valliyoor	10.40	-	-	-	7.22	3.17	-	-
3	Total	53.10	-	-	6.04	25.93	15.57	1.97	3.58

HE - High Erosion,ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

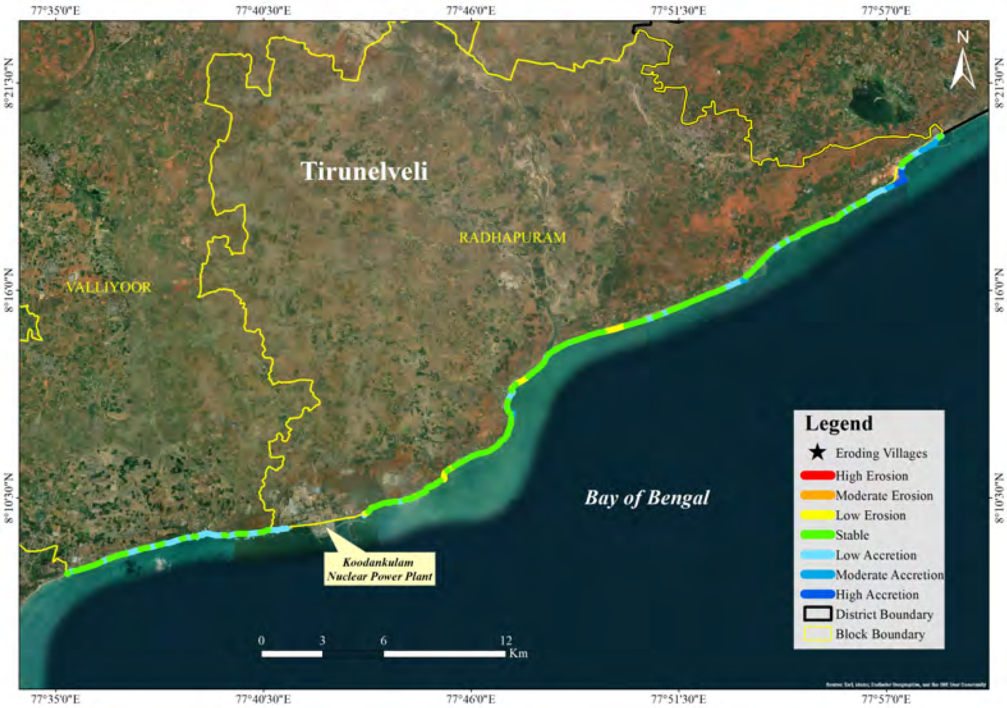


Figure 114 Shoreline Change map of Tirunelveli District from 1992 - 2022

Table 81. Accretion dominant villages in Tirunelveli District.

S. No.	District Name	Block Name	Village Name	Length in Km
1	Tirunelveli	Radhapuram	Kuttam	2.85

4.13.3 SLR Projections and Coastal Inundation in Tirunelveli District

The projection of the total trend of SLR for the Tirunelveli coast based on the SSP2 4.5 scenario (Medium Projection) for the near century is estimated as an average of 20.2 cm (Figure 115). The coastal inundation due to the rise in sea level is projected to be about 120 ha. The inundation effect is mostly on sandy coasts and agricultural land (Figure 116).

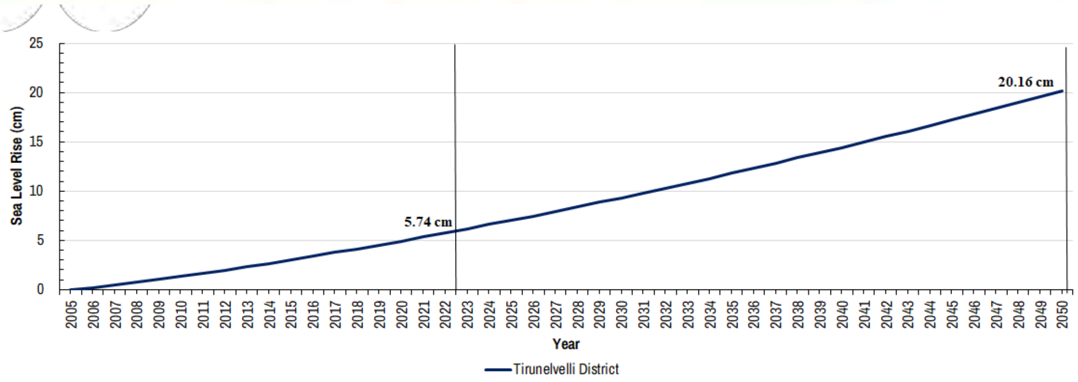


Figure 115 Projected SLR of Tirunelveli District under SSP2- 4.5 (cm) for the Near Century

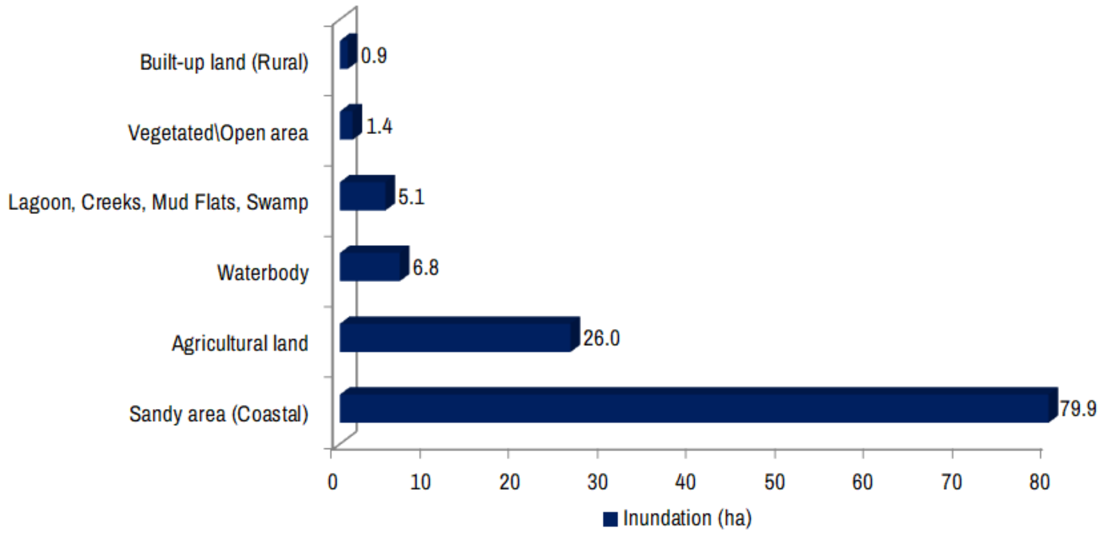


Figure 116 Impact of coastal inundation on land use land cover of Tirunelveli District.

4.13.4 Coastal Risk Assessment of Tirunelveli District

In both the baseline and near-century scenarios, the coastline of Tirunelveli is categorized as having moderate hazard prone category, with 45.4 km and 36.8 km falling under the moderate category (Table 82). However, in terms of vulnerability and exposure, the Kanyakumari coast is classified as high - very high with 37.7 km and 30.5 km, respectively (Figure 117). Thus, the risk for the coastline is moderate to high.

Table 82. Integrated Coastal Risk Assessment for Tirunelveli District (km).

S. No.	Tirunelveli	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	1.1	0.8	8.7	3.0	14.0	10.4
2	Low	3.1	2.6	1.7	9.9	11.2	8.2

3	Moderate	45.4	36.8	5.4	10.1	14.1	12.4
4	High – Very High	3.8	13.3	37.7	30.5	14.1	22.5
	Total	53.5	53.5	53.5	53.5	53.5	53.5

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

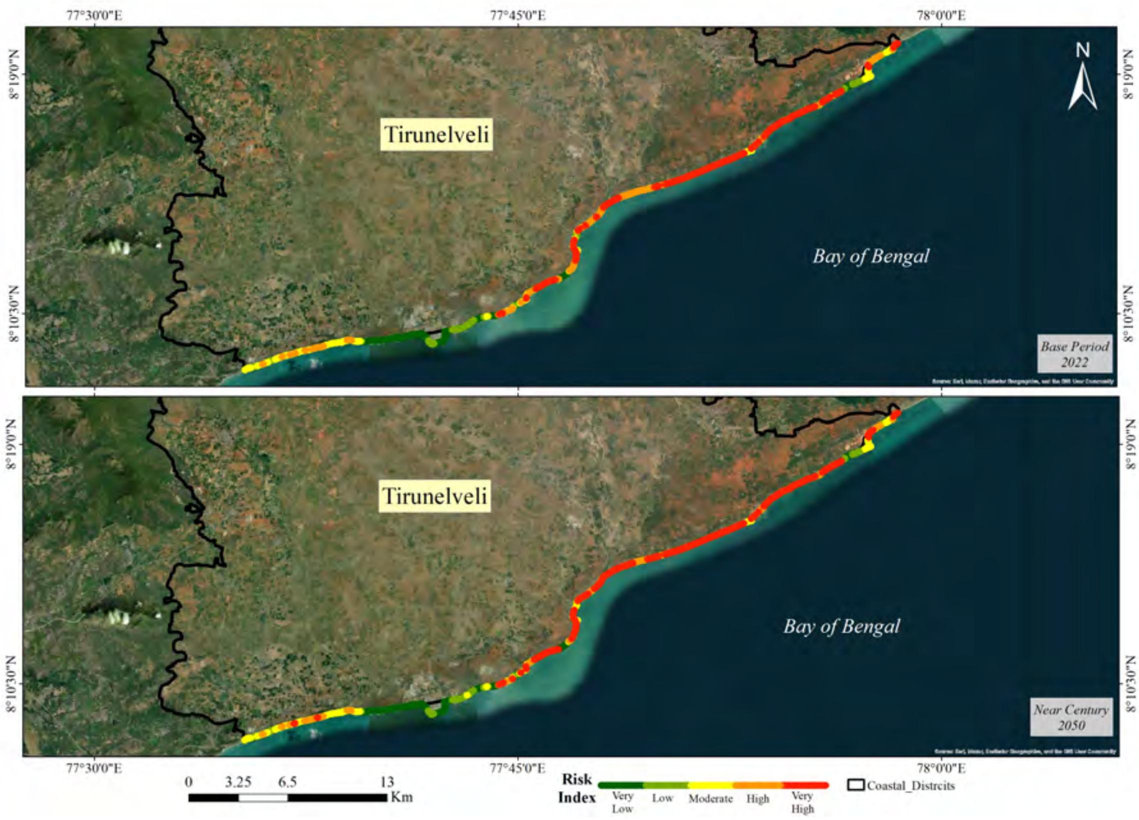


Figure 117 Coastal Risk Index map of Tirunelveli District

4.14 Kanyakumari

The district extends between 8°03' to 8°35' of the northern latitudes and 77°15’ and 77°36' of the eastern longitudes (Figure 118). The district is part of the Gulf of Mannar 11.5 km and the West coast 60km and has four coastal blocks such as Agastheeswaram, Rajakkamangalam, Kurunthancode, Killiyoor, and Munchirai, covering 72 km of coastal length. The district lies in the southern tip of the country at the confluence of the Bay of Bengal in the east, the Indian Ocean in the south, and the Arabian Sea in the west, with a coastal length of 72 km. Sand dunes coasts are predominant along the east, and barrier beaches are along the west. The southern tip is a major spot for tourist attractions. The district flourishes from both southwest monsoon and northeast monsoon season. Theroor Wetland complex at Suchindram and Vembannur Wetland complex are the Ramsar sites in the district.

According to the Tamil Nadu Fisheries Department in 2022, the district has a fisherman population of 83032 individuals.

Various coastal geomorphic features can be observed along the coast of Kanyakumari district, including beaches, beach ridges, a cliffed coast, sand dunes, and beach terraces. However, it is important to note that these marine landforms are limited in width, typically measuring less than 1km. This restraint is primarily due to the high relief of the nearby inland areas, which indicates the slope of the Western Ghats in comparison to the Eastern Coast (TN-ENVIS, 2020).

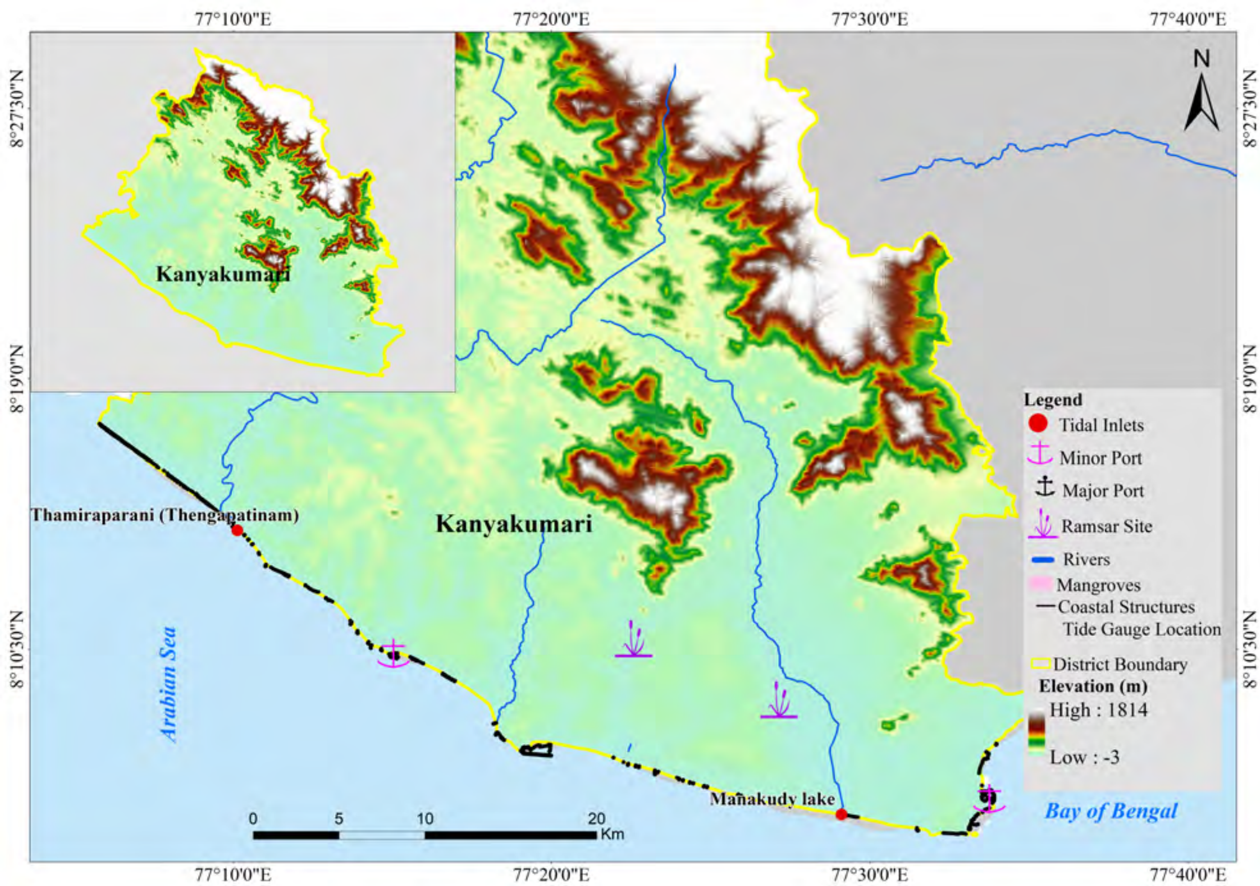


Figure 118 Coastal Profile map of Kanyakumari District.

4.14.1 Land use Land Cover (LULC) of Kanyakumari District

The LULC assessment conducted for Kanyakumari District in 2022 (Figure 119) revealed that the dominant land use is agriculture or crop land (44 %), followed by Forest (32.7 %), Built-up land (Rural) (13.6 %), Waterbodies (4.4 %) (Table 83). Kanyakumari district having the highest forest cover compared to other coastal districts in Tamil Nadu.

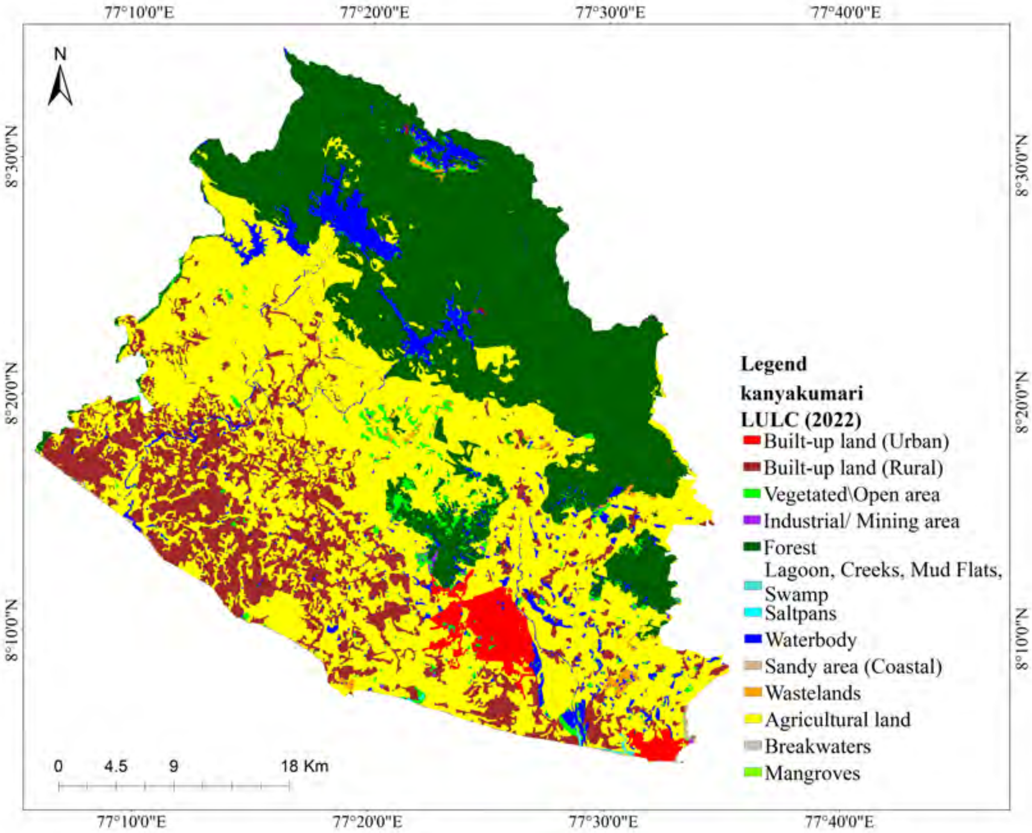


Figure 119 Land use and Land Cover (LULC) of Kanyakumari District

Table 83. Land use Land Cover Assessment of Kanyakumari District.

S. No.	Land use Land Cover	Area (ha)	% of Total area
1	Built-up land (Urban)	4180	2.5
2	Built-up land (Rural)	23009	13.6
3	Vegetated/Open area	3158	1.9
4	Industrial/ Mining area	202	0.1
5	Forest	55216	32.7
6	Lagoon, Creeks, Mud Flats, Swamp	103	0.1
7	Saltpans	25	0.01
8	Waterbody	7466	4.4
9	Sandy Beaches	295	0.2
10	Wastelands	768	0.5
11	Agricultural land	74198	44.0
12	Mangroves	32	0.02
TOTAL		168667	100.0

4.14.2 Assessment of the Shoreline Change for Kanyakumari District (1992-2022)

The results obtained from the LRR analysis show that within 30 years (1992–2022), about 0.04 km of coastal length under high erosion, 0.44 km of coastline under moderate erosion, 38.48 km of coastline under low erosion, while 1.37 km under high accretion (Table 84). Out of 38.48 km of low erosion, 9.42 km of coast under Munchirai block indicates the vulnerability of shoreline changes. The erosion rate is 1.0 m/year, while the accretion rate is 1.6 m/year. The eroding hotspot villages were identified, and the length was calculated. It is observed that Symon colony, Midalam B, Thengapattanam, Ezhudesam C, Ezhudesam B, and Kollancode B are highly eroded (Table 85), while Kadiapattanam village observed with high accretion (Table 86) (Figure 120). The study revealed that about 89 ha of land loss and 70 ha of land gain were observed in the Kanyakumari district area over a period of 30 years.

Table 84. Shoreline change assessment of Kanyakumari District.

S. No.	Block Name	Coast Length (km)	HE	ME	LE	Stable	LA	MA	HA
1	Agastheeswaram	18.01	0.04	0.03	8.74	7.60	1.60	-	-
2	Rajakkamangalam	17.47	-	-	8.27	6.57	2.24	0.30	0.09
3	Kurunthancode	16.78	-	0.09	7.79	4.60	2.62	0.40	1.28
4	Killiyoor	7.79	-	-	4.26	2.21	1.07	0.25	-
5	Munchirai	11.23	-	0.32	9.42	1.43	0.05	-	-
	Total	71.28	0.04	0.44	38.48	22.41	7.58	0.96	1.37

HE - High Erosion,ME - Moderate Erosion, LE - Low Erosion, LA - Low Accretion, MA - Moderate Accretion, HA - High Accretion

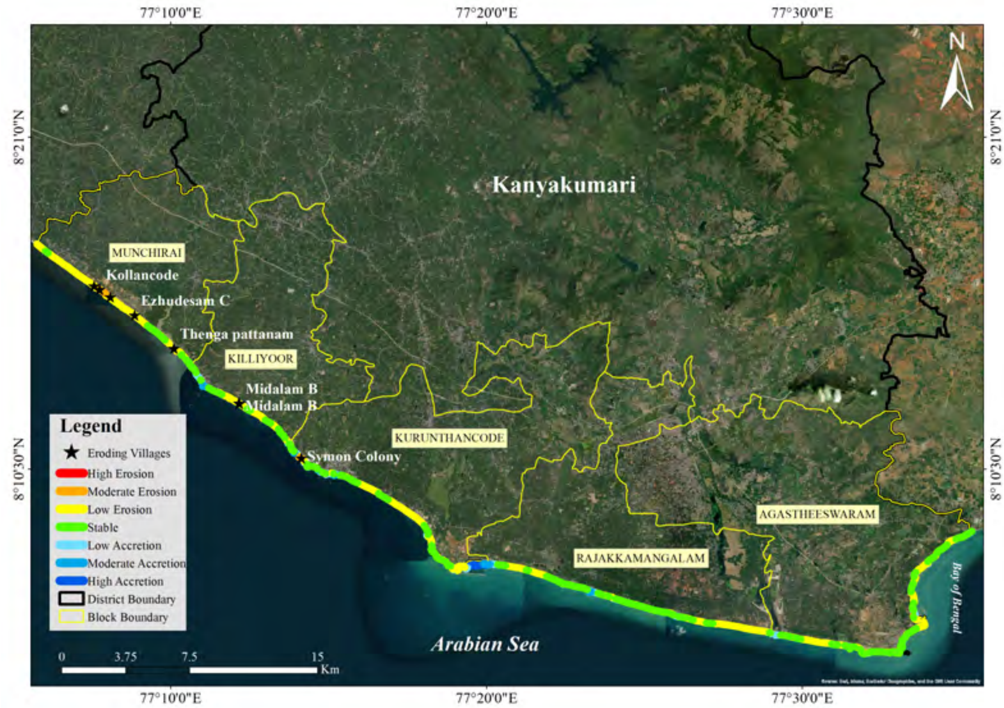


Figure 120 Shoreline Change map of Kanyakumari District from 1992 - 2022

Table 85. Eroding hotspots of Kanyakumari District.

S. No.	District Name	Block Name	Village Name	Length in Km
1	Kanyakumari	Kurunthancode	Symon Colony	0.17
2		Killiyoor	Midalam B	0.1
3		Munchirai	Thenga pattanam	0.18
4			Ezhudesam C	0.4
5			Ezhudesam B	0.51
			Kollancode B	0.81

Table 86. Accretion dominant villages in Kanyakumari District.

S. No.	District Name	Block Name	Village Name	Length in Km
1	Kanyakumari	Kurunthancode	Kadiapattanam	2.26

4.14.3 SLR Projections and Coastal Inundation in Kanyakumari District

The projection of the total trend of SLR for the Kanyakumari coast based on the SSP2 4.5 scenario (Medium Projection) for the near century is estimated as an average of 20.2 cm (Figure 121). The coastal inundation due to the Sea Level Rise is projected as about 31 ha under SSP2 4.5. The inundation effect is mostly on sandy coasts and agricultural land (Figure 122).

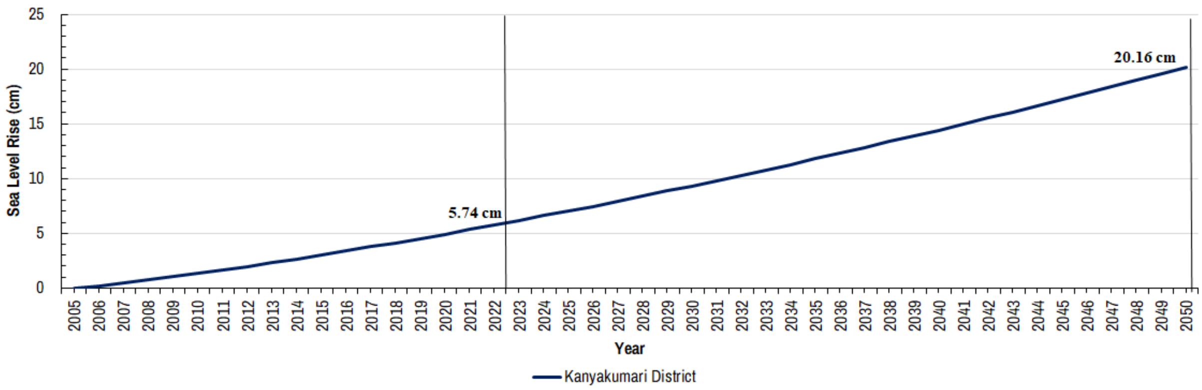


Figure 121 Projected SLR of Kanyakumari District under SSP2- 4.5 (cm) for the Near Century

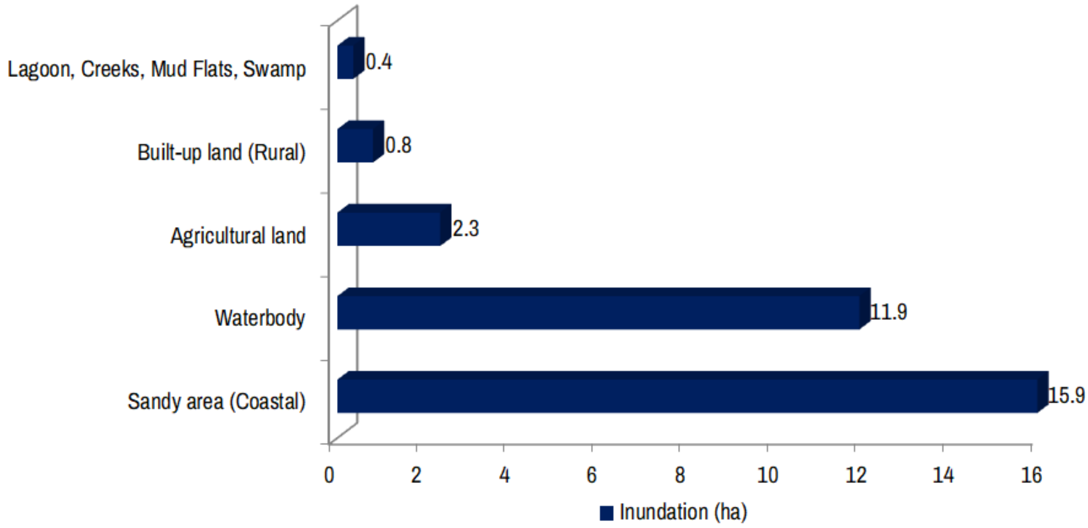


Figure 122 Impact of coastal inundation on land use land cover of Kanyakumari District.

4.14.4 Coastal Risk Assessment of Kanyakumari District

In both the baseline and near-century scenarios, the coastline of Kanyakumari is categorized as having moderate hazard prone category, with 49.3 km and 40 km falling under the moderate category (Table 87) (Medium Projection). In terms of vulnerability and exposure, the Kanyakumari coast is classified as high – very high, with 35.6km and 63.6 km of coastline falling in this category (Figure 123). Consequently, the risk for the coastline has slightly increased both in the baseline and projected periods.

Table 87. Integrated Coastal Risk Assessment for Kanyakumari District (km).

S. No.	Kanyakumari	HB	HNC- 2050	VL	EX	RB	RNC - 2050
1	Very Low	3.5	2.6	19.4	0.0	15.8	11.6
2	Low	2.3	1.9	9.1	3.9	17.2	13.1
3	Moderate	49.3	40.0	10.0	6.7	12.7	11.6
4	High – Very High	19.0	29.7	35.6	63.6	28.4	37.9
	Total	74.2	74.2	74.2	74.2	74.2	74.2

HB - Hazard Base Period, HNC- Hazard Near Century – 2050, VL- Vulnerability, EX -Exposure, RB - Risk Base, RP - Risk Near Century – 2050

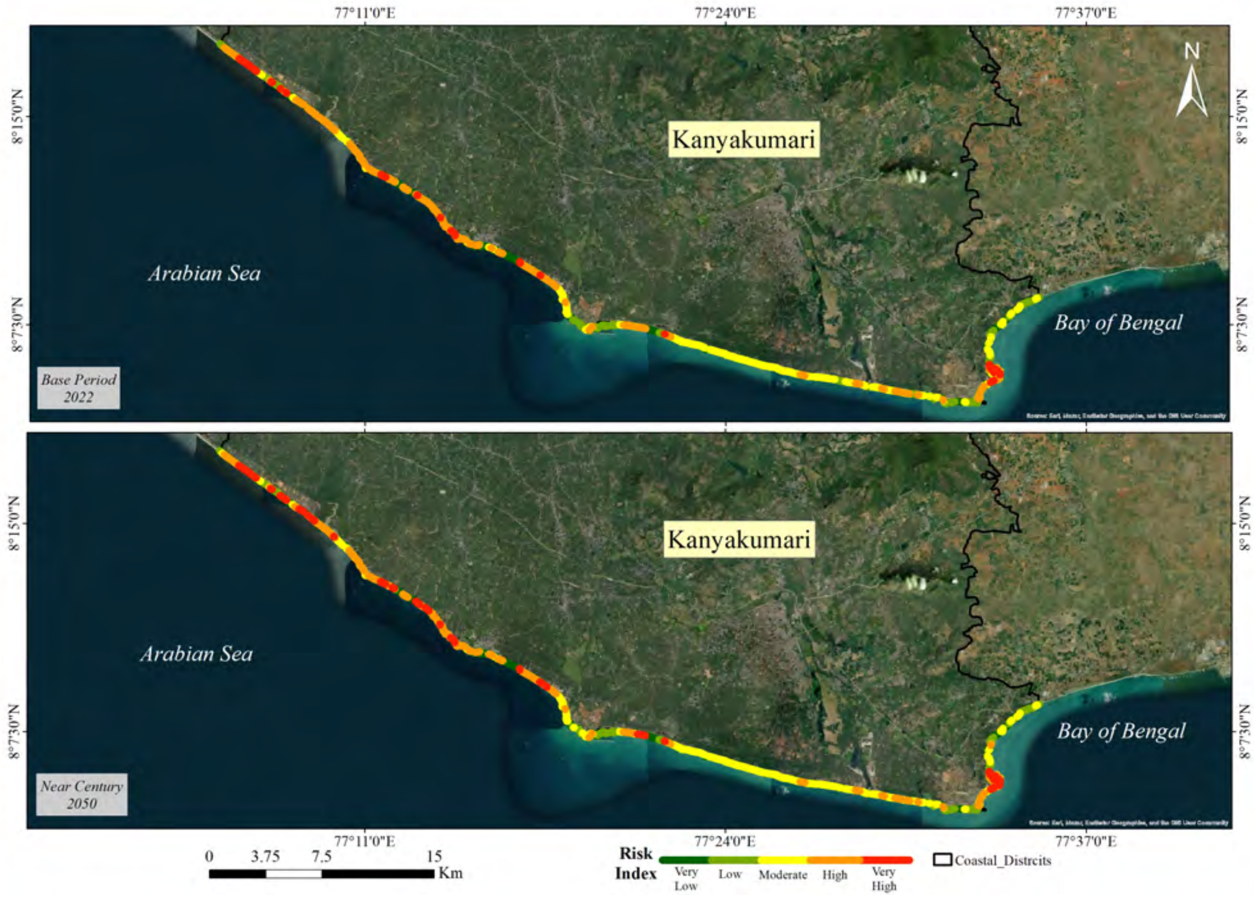


Figure 123 Coastal Risk Index map of Kanyakumari District

5. Coastal Risk Assessment of Tamil Nadu

The Coastal Risk Index for the Tamil Nadu Coastline was assessed for the base period of 2022 and projected to 2050, considering coastal hazards, vulnerability, and exposure. The analysis showed that the coast is highly vulnerable to climate-related hazards such as sea level rise, cyclones, and shoreline changes. Shoreline change rates over the past 30 years indicated erosion in 36% of the coast and accretion in 30%. The projected sea-level rise by 2050 is 19.71 cm, with districts like Tiruvarur, Nagapattinam, and Thanjavur being most affected. Severe cyclonic storms have increased in frequency since 2016. The coastal hazard index identified districts like Nagapattinam and Chengalpattu as highly susceptible. Vulnerability assessments showed high vulnerability in districts like Tiruvarur, Nagapattinam, and Chengalpattu due to factors such as high salinity and low elevation. Districts like Kanyakumari, Chennai, and Cuddalore had over 60% of their coastlines exposed to climate change. Districts like Tiruvarur, Nagapattinam, Chennai, Tiruvallur, Cuddalore, and Chengalpattu identified as High to very high coastal risks for both the base period and near century.

The assessment for hazard and risk has been conducted for both the base period and future period, revealing a significant increase in the high to very high risk category by approximately 9% and 11% of the coastline for each respective classification (Figure 124).

The integration of hazards, vulnerability, and exposure allows for a comprehensive coastal risk assessment, providing valuable insights for stakeholders to adapt and mitigate the impacts of climate change on the Tamil Nadu coast. Overall, the study highlights the urgent need for coastal management strategies and adaptation measures to address the increasing risks posed by climate change on the vulnerable coastal areas of Tamil Nadu.

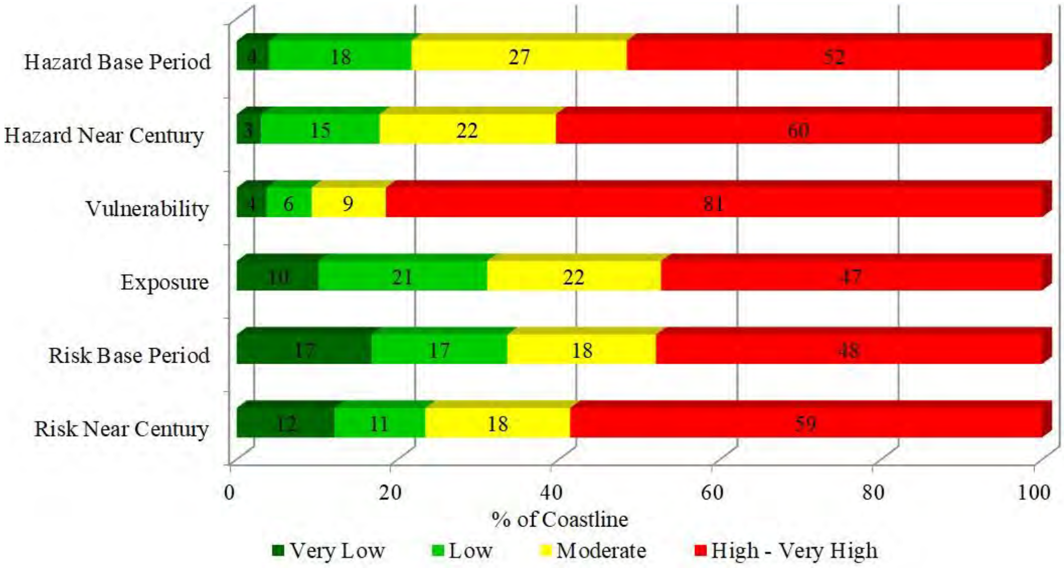


Figure 124 Percent of Tamil Nadu Coastline under different Risk Category

6. Climate Adaptation Strategies for Coastal Districts of Tamil Nadu

In low-lying coastal areas, both urban and rural regions face significant risks from climate-induced changes in oceanic and cryospheric conditions, irrespective of their geographical location or level of development, according to the IPCC AR6 report with high confidence. The IPCC's 2014 assessment outlines a spectrum of climate change impacts that are expected to alter local weather patterns. Among these impacts, Sea Level Rise (SLR) stands out as a primary driver, exacerbated by cyclone-induced waves, which can result in heightened coastal erosion, tidal inundation, and storm surges, leading to localized flooding (Black et al., 2017).

Adaptation emerges as a crucial element in the long-term response to climate change, playing a pivotal role in safeguarding human populations, livelihoods, and ecosystems. Proactive measures taken by governments, industries, and communities are imperative for enhancing resilience against natural hazards and climate-related impacts, necessitating a comprehensive approach to shaping responses. Adaptation strategies primarily aim to mitigate risk by addressing vulnerabilities, exposures, and hazards. The reduction of vulnerability, exposure, and hazard potential can be achieved through different policy and action choices suitable to the particular area.

6.1 Climate adaptation from global to local level approach

Projections suggest that the proportion of the global population residing in coastal regions will persistently rise *(Neumann et al., 2015).* Simultaneously, the impacts of climate change, notably regional sea level rise and its associated effects, present significant risks to coastal communities and shorelines. Consequently, the prioritization of coastal safety becomes increasingly paramount *(Temmerman et al., 2013; Firth et al., 2014).* To maintain acceptable levels of coastal safety, various coastal engineering solutions are being deployed, which can be categorized into two main types: grey and green infrastructure (Figure 90) *(Schoonees et al., 2019).* By reducing greenhouse gas (GHG) emissions, not only can risks be reduced, but a wider array of adaptation options can also become available.

Coastal regions worldwide are implementing a diverse array of adaptation measures to mitigate the impacts of climate change, particularly in Low-Lying Island and Coastal (LLIC) areas. These measures encompass both major infrastructure projects, such as the construction of seawalls, groynes, revetments, and rip-raps to armor coastlines, as well as softer approaches like beach nourishment and dune restoration. Additionally, efforts are underway to reclaim land by creating new areas seaward and upward. Ecosystem-based strategies, including vegetation planting and coral farming, community-centered approaches like social networks, education campaigns, and economic diversification, and institutional innovations such as marine protected areas and evacuation plans, are also being deployed.

Tamil Nadu extends a diverse coastline stretching over 1076 km, characterized by varied geological and geomorphic features. This coastline plays a pivotal role in supporting the state's major economic sectors, including fisheries, agriculture, tourism, transportation, and communication. However, the region faces significant threats from climate change, including sea level rise, cyclones, shoreline changes, and storm surges. Coastal protection and management have emerged as critical challenges for development in the face of these pressures.

Nevertheless, Tamil Nadu possesses the potential for coastal Blue carbon ecosystems to naturally protect themselves from the impacts of climate change. Therefore, adaptation action planning in the Tamil Nadu coastal region prioritizes Nature-Based Solutions, recognizing the inherent resilience of coastal ecosystems.

6.2 Tamil Nadu Coastal Restoration Mission

The “Tamil Nadu Coastal Restoration Mission” [G.O. (Ms). No101, TN. Govt. 2021] was implemented with the following objectives such as

1. Preventing Sea Erosion
2. Reducing Marine pollution
3. Conserving marine biodiversity

In this, the "Tamil Nadu Sustainably Harnessing Ocean Resources and Blue Economy (TN-SHORE)" project is focused on the resilience and sustainable utilization of coastal resources through the integration of resilient and circular blue economy, enhance livelihoods, and capacities for a greener future (Table 88).

The following components are the focus area of the TN-SHORE Project,

Table 88. Tamil Nadu Coastal Restoration Mission Components

S.No	Action Components and Sub Components
1.	Enhance Coastal Biodiversity
	1. Biodiversity Conservation Park, Kadambur, Chengalpattu. 2. Sea Turtle Conservation Centre, Chennai and Nagapattinam. 3. International Dugong Conservation Centre, Manora, Thanjavur. 4. Coastal Wetlands Conservation and Restoration, Pallikaranai, Chennai.
2.	Coastal Protection – Eco system Based Approach and Living Shoreline
	1. Special Purpose Vehicle "Tamil Nadu Blue Carbon Agency". 2. Enhancing Coastal Resilience: Mangroves, Seagrass, and Blue Carbon Solutions. 3. Erosion Control and coral restoration, Kariyachalli Islands, Gulf of Mannar. 4. Strengthening Coastal Management through Integrated Coastal Zone Management (ICZM), Marine Spatial Planning (MSP), Coastal Management Plan (CMP) for Critically Vulnerable Coastal Areas (CVCA), Integrated Management Plan (IMP), Capacity building and outreach initiatives.
3.	Improving Livelihoods
	1. Blue flag beaches. 2. Sustainable tourism. 3. Diversified Livelihood for thriving Blue Economy.
4.	Pollution Abatement
	1. Meendum Manjappai – Plastic Circularity. 2. Climate Smart Coastal Villages. 3. Ennore creek Restoration.
5.	Project Management
	1. Enabling project execution and Management

6.3 Existing Coastal Adaptation Strategies

The description of the following activities below is based on mitigation and adaptation options mentioned for the state (Table 89). The following are the coastal area management strategies,

1. Develop a Tamil Nadu Integrated Coastal Protection Plan (TN-ICPP) to adapt to projected sea level rise, enhanced intensities of cyclones, storm surges and extreme rainfall.
2. Avert enhanced coastal erosion due to Climate change & and protect the coastal zone.
3. Strengthen the resilience of coastal communities in view of projected climate change.
4. Avert enhanced saltwater intrusion in groundwater and ensure water security in coastal Tamil Nadu.
5. Conserve biodiversity in the coastal zone.
6. Avert pollution of water and soil in the coastal zones caused by industrial (power plants & and other industries) and domestic wastewater and solid water management (SWM) practices.

Table 89. State Activities & Benefits

S.No	Activities & Benefits
1	Shelterbelt plantation and Restoration of green cover in cyclone-affected area
	Cyclones cause heavy damage to the green cover of the State. Restoration of the green cover promotes the buffer against cyclone impacts Promoting social forestry including tree growing on homesteads, and other agro-forestry systems involving local people, rural communities, and NGOs would be important to increase the green cover.
2	Raising Palmyrah palm plantation
	Panaimaram (Palm tree) is the State tree of Tamil Nadu that has been slowly vanishing from the landscape. Palmyra trees not only give economic benefits but also prevent soil erosion and help recharge the water table
3	Mangrove Conservation and Management
	Promoting community-based mangrove restoration and conservation Mangrove Fishery Farming System Ecotourism Mangroves protect coastal areas against storm surges, high waves and tsunami It acts as the water filtration in treating the effluents Carbon sequestration in climate regulation Nursing and breeding ground for the fisheries Promotes tourism

4	Gulf of Mannar Biosphere Reserve protection
	It is one of the world's richest regions from a marine biodiversity perspective. It promotes the livelihood opportunities and economic values.
5	Ensure coastal Livelihood of Fishermen and Strengthen the resilience of coastal communities in view of projected climate change
	There is a need to develop strategies that can be adopted by the local communities in order to adapt to the wrath of climate change, like shift to more resilient agricultural, aqua culture mariculture, sea weed farming etc
6	Integrated coastal zone management(ICZM)
	It involves the response strategies such as protect, accommodate and retreat.
7	Shoreline Management and Avert enhanced coastal erosion due to climate change and protect the coastal zone
	Shore protection can be of two types, hard and soft engineering. Hard engineering involves any physical construction to restrict the entrance of seawater in inland areas like sea walls, groynes, etc. whereas soft engineering involves plantation of trees that would naturally act as a barrier to strong surges and high-velocity winds.
8	Disaster management risk project
	Disaster Risk Reduction or Disaster Preparedness is an important aspect when it comes to coping up with the unprecedented climate hazards. The preparedness to hazards safe guards the lives of the communities and properties

6.4 Prioritizing the Coastal Adaptations towards Climate Change

In the alluvial plot Figure 125, the connections between various actions, climate risks, and coastal districts are visually represented. The plot illustrates how different actions are associated with specific climate risks in different coastal districts. The actions include "Coastal Livelihood Management," "Hard Measures," "Nature Based Solutions," "Soft Measures," and "Technology." These actions are aimed at addressing various climate risks such as "Coastal Erosion," "Coastal Inundation due to Sea Level Rise," and "Tropical Cyclones/Storm Surges."

Each action is linked to specific climate risks, demonstrating the strategies employed to mitigate or adapt to the identified risks. For instance, "Coastal Livelihood Management" is associated with all three climate risks, indicating a comprehensive approach to addressing multiple challenges. Based on the alluvial plot (Figure 125) and Table 91, it is apparent that Coastal Livelihood management and Nature based solutions takes a prominent position among the various categories.

Nature based solutions or Ecosystem-based adaptation is a cost-effective coastal protection tool that can have many co-benefits, including supporting livelihoods, contributing to carbon sequestration and the provision of a range of other valuable ecosystem services (IPCC AR6). It uses the range of opportunities for the sustainable management, conservation, and restoration of ecosystems to provide services that enable people to adapt to the impacts of climate change (Narayan et al., 2016; Moosavi, 2017). Coastal Livelihood management involves the Socio institutional adaptation responses, including community based adaptation, capacity-building, participatory processes, institutional support for adaptation planning and support mechanisms for communities are important tools to address climate change impacts It is emphasized that Armouring of the coast by hard coastal defences is commonly used to prevent inundation from extreme water levels and wave overtopping in the megacities, adequately engineered hard coastal defences are considered to be successful options an efficient adaptation option in the long run (Hinkel et al., 2018).

The coastal area of the Tamil Nadu is well occupied by the Major Coastal Blue carbon ecosystems such as Mangroves, Coral reefs, Sea grass and Salt Marshes (Table 90). The districts which are more vulnerable due to Erosion such as Tiruvallur, Cuddalore, Mayiladuthurai, Nagapattinam, Ramanathapuram and Thoothukudi. In order to reduce the erosion, it is recommended soft measures, living shoreline and Nature based solutions such as conservation and restoration Mangroves, Coastal Plantations, Sandunes, salt marshes etc. plays the pivotal role in mitigating climate change impacts. The districts which are more vulnerable due to Sea Level Rise induced inundation under SSP2-4.5 Scenario such as Tiruvallur, Chengalpattu, Nagapattinam, Tiruvarur, Thanjavur, Ramanathapuram and Thoothukudi. Nature-based solutions and Livelihood management seem to have higher frequencies compared to hard measures, indicating a preference for more environmentally friendly approaches. The districts which are more vulnerable due to Cyclones such as Tiruvallur, Chennai, Chengalpattu, Villupuram, Cuddalore, Mayiladuthurai, Nagapattinam, and Tiruvarur requires the shelter belt plantations and ecosystem based storm surge barriers Overall, the alluvial plot provides a concise visualization of the interconnectedness between actions, climate risks, and coastal districts, offering insights into the strategies implemented for coastal resilience and adaptation efforts. The dataset provides granular insights into each coastal district's specific vulnerabilities and adaptive capacities. By mapping actions to respective districts, stakeholders can tailor interventions to address localized challenges effectively. Priority areas for intervention can be identified, guiding resource allocation and policy formulation at both regional and national levels. In conclusion, this comprehensive analysis underscores the importance of integrated coastal risk management strategies ensuring the coastal livelihood management and Nature based solutions in building resilience against climate change-induced threats. By harmonizing diverse approaches and leveraging local knowledge, coastal communities can navigate uncertain futures with resilience and adaptability.

Table 90. Area of Coastal Habitats in Tamil Nadu

		Area of Coastal Habitats along Tamil Nadu Coast (ha)					
S.No	Districts	Mangroves	Coastal Plantations (1 km Buffer)	Sand dunes (500m Buffer)	Sea grass	Coral Reefs	Salt Marshes
1	Tiruvallur	103	40	387			6100
2	Chennai	82	73	59			
3	Chengalpattu	5	794	405			
4	Villupuram	102	347	231			
5	Cuddalore	979	196	249			
6	Mayiladuthurai	524	811	395			
7	Nagapattinam	629	1155	236			
8	Thiruvarur	1922	0	0			
9	Tanjavur	1171	282	5	87300		
10	Pudukottai	219	459	3			
11	Ramanthapuram	383	1736	162		9430	
12	Thoothukudi	318	155	120			
13	Tirunelveli	0	314	49			
14	Kanyakumari	36	3363	137			
	Total Area (ha)	6473	9725	2438	87300	9430	6100

Source: Ramesh et al., 2008; Geevarghese et al., 2018, Viswanathan et al., 2020; NCCR 202

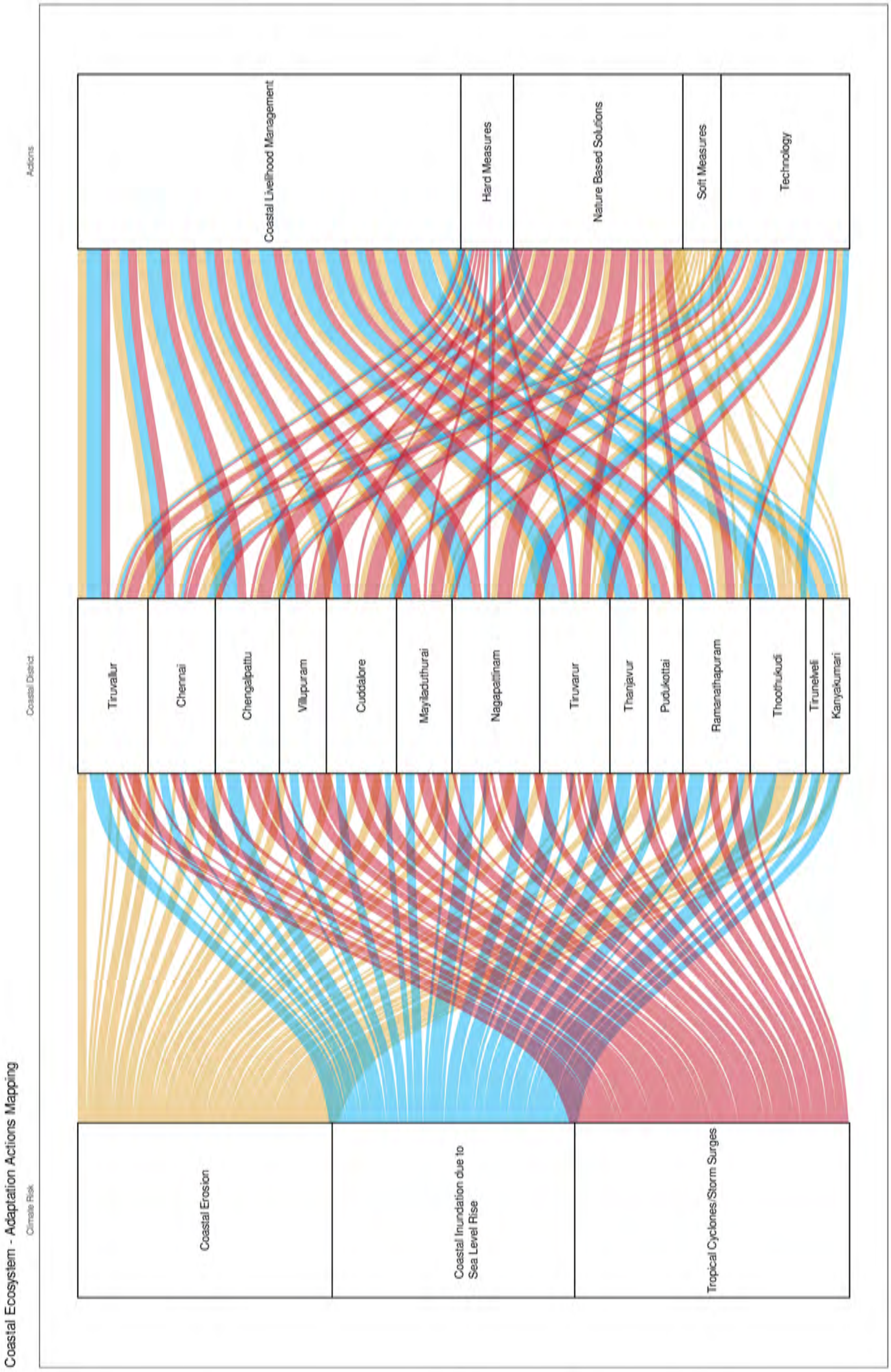


Figure 125 Coastal Area Management Adaptation Actions Mapping

Table 91. List of Coastal Adaptation Strategies

S.No	List of Coastal Adaptation Strategies
1	Coastal Livelihood Management
1.1	Climate Literacy
1.2	Livelihood Diversification
1.3	Prioritizing Indigenous Knowledge
1.4	Insist Accommodation and relocation
1.5	Promoting Community Based Restoration and Conservation
2	Hard Measures
2.1	Construction of Sea walls
2.2	Construction of Groynes
2.3	Construction of Nearshore reefs
2.4	Construction of offshore reefs
2.5	Construction of breakwaters
2.6	Construction of offshore breakwaters
2.7	Construction of revetments
2.8	Construction of ripraps
2.9	Construction of Sea Dike
2.10	Construction of Storm surge barrier
2.11	Construction of salt water Intrusion barriers
3	Nature Based Solutions
3.1	Protection, Conservation and Restoration of Coastal plantations
3.2	Protection, Conservation and Restoration of Mangrove plantations

S.No	List of Coastal Adaptation Strategies
3.3	Protection, Conservation and Restoration of Seagrass plantations
3.4	Protection, Conservation and Restoration of coral reefs
3.5	Protection, Conservation and Restoration of Bio shield
3.6	Afforestation of areas close to water ways
3.7	Protection, Conservation and Restoration of sand Dune vegetation
3.8	Protection, Conservation and Restoration of Salt marshes
4	Soft Measures
4.1	Artificial Beach Nourishment
4.2	Establishing artificial reefs made from bio-rock materials
4.3	Bio shields/Vegetation
4.4	Dune Stabilization
4.5	Application of Geo synthetics such as Geo synthetic soil retaining wall, geo bags, geo-cells, geo-grids and geo textiles
4.6	coconut fibre blankets
4.7	Bamboo breakwaters
5	Technology
5.1	Early Warning System
5.2	Elevating Structures
5.3	Living Shoreline
5.4	Floating Structures

6.5 Living Shoreline Concept – Hybrid Solution

A living shoreline is a shoreline stabilization method employed along estuarine coasts, bays, sheltered coastlines, and tributaries. It primarily consists of native materials and incorporates vegetation or other living, natural elements alongside harder shoreline structures like oyster reefs or rock sills for increased stability. Living shorelines serve to maintain the natural land-water interface, reduce erosion, and provide habitat value while enhancing coastal resilience. These techniques are essential for managing coastal erosion, improving intertidal habitat for marine life, and fortifying coastal communities and ecosystems against sea level rise, climate changes, and extreme weather events (NOAA, 2015) Figure 126.

NOAA advocates for the use of living shoreline approaches as they promote coastal resilience and ecosystem functionality, all while minimizing disruption to subtidal habitats and avoiding land reclamation.

6.5.1 Benefits of NOAA's living shorelines principles

i. Preservation of Natural Sediment Supply: Allows for the maintenance of existing ecosystem services by preserving natural sediment supply and minimizing disruption to coastal habitats.

ii. Mitigation of Adverse Impacts: Reduces adverse effects on adjacent habitats caused by bulkheads and other hardened structures, including erosion, habitat loss, and chemical leaching.

iii. Effective Shoreline Stabilization: Provides successful shoreline stabilization through dampening wave energy and reducing erosion, particularly through the use of marshes and oyster reefs.

iv. Long-Term Stability: Becomes more stable over time as living elements such as plants, roots, and oyster reefs grow, with expected elevation maintenance relative to sea level rise.

v. Superior Performance during Storm Events: Outperforms hardened shorelines during severe storms, reducing damage and erosion while maintaining stability.

vi. Enhanced Habitat Function: Provides greater habitat function for fish and marine resources compared to hard shorelines, offering valuable ecosystem services such as food production, water quality improvement, and storm protection.

vii. Minimization of Ecosystem Effects: Minimizes ecosystem effects from hardened shorelines by reducing habitat trade-offs and preserving existing shoreline and nearshore habitats.

viii. Reduction of Habitat Trade-offs: Minimizes habitat trade-offs by avoiding or minimizing encroachment into subtidal areas and reducing the footprint of hard, unnatural structures, thus preserving natural habitats and species diversity.

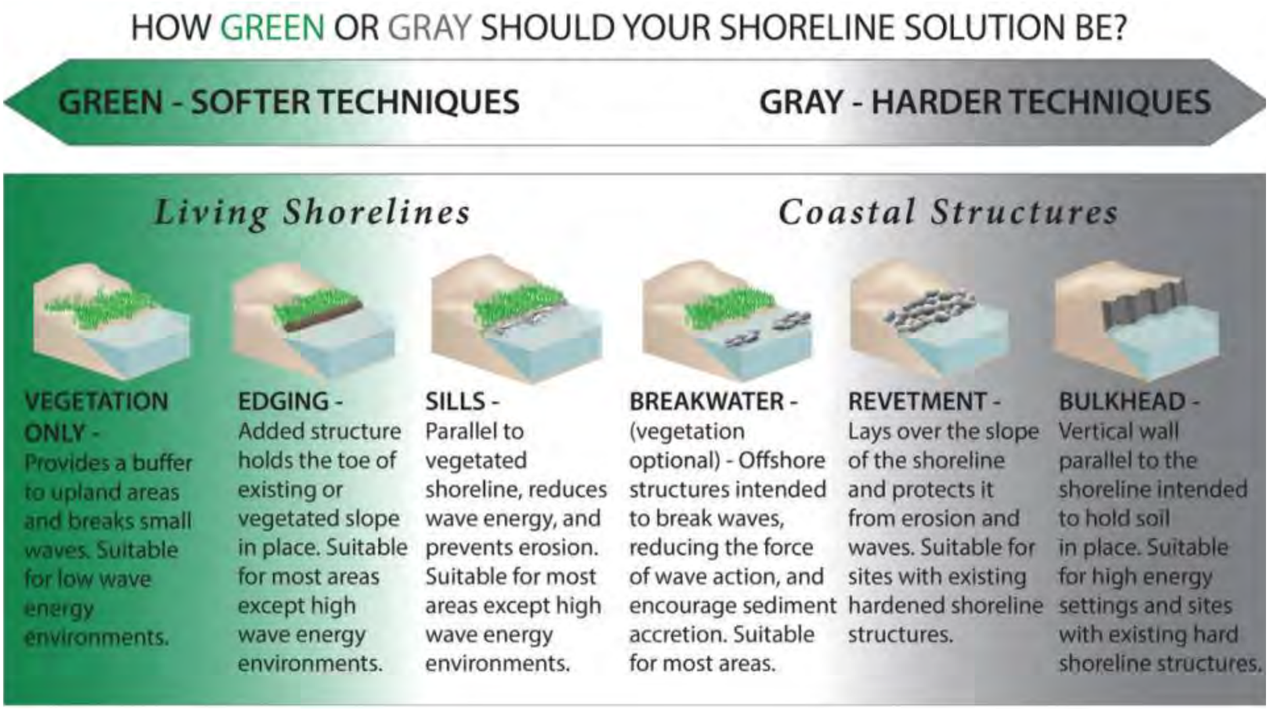


Figure 126 A continuum of green (soft) to gray (hard) shoreline stabilization techniques. Source: NOAA 2015, SAGE 2015

7. Knowledge Dissemination

As a part of "Operationalization of Climate Studio" knowledge dissemination was carried out through a capacity building program aimed at raising awareness among policymakers about the impacts of climate change on the coastal ecosystem. Officers from four departments - Water Resources (Anti-Sea Erosion), Forest, Fisheries, and Disaster Management - participated in a three two-day capacity-building training program. The program was attended by Assistant Engineers from Public Works Department (PWD), Foresters, Forest Range Officers, Tehsildars, and Special Deputy Collectors from Disaster Management and Assistant Engineers from Fisheries Department, totaling approximately 35 officers from all 14 coastal districts of Tamil Nadu.

The primary objective of the training program is to assist the Tamil Nadu coastal region in achieving its climate change response goals through adaptation measures. Specifically, the program focuses on understanding coastal hazards, vulnerabilities, and risks to effectively address these challenges. The program aims to provide knowledge and scientific methodologies to assess and manage the behavioral changes in coastal areas under climate risks.

Figure 127 Release of the "Training Manual" on "Climate Risk Assessment and Adaptation Plan of Tamil Nadu".

A training manual on "Climate Risk Assessment and Adaptation Plan of Tamil Nadu" was released by Dr. V. Selvam, Executive Director of Speed Trust; Dr. A. Ramachandran, Founder Director and Emeritus Professor of CCCDM; Dr. Kurian Joseph, Professor and Director of CCCDM; and Dr. K. Palanivelu, Professor of CCCDM, during the first capacity-building program. This manual equips officers from various departments with the necessary skills to assess the impacts of climate change on coastal areas in Tamil Nadu. The training provides officers with the knowledge to utilize coastal inundation and shoreline change data for accurate evaluations and conduct effective coastal risk assessments.

By participating in this training program, officers gain essential expertise in managing the coastal ecosystem in response to evolving climatic conditions, ensuring resilience and sustainability in Tamil Nadu's coastal region.

Figure 128. Glimpses of the Three Capacity Building programme for Coastal Ecosystem.

8. Way Forward

The Climate Studio has completed a multi-sectoral climate risk assessment, identifying districts with high and very high-risk prone areas. The State Government has initiated climate change mission activities at the district level, with the District Climate Change Mission working with all departments in line with the State Action Plan. Green Fellows have been appointed in each district to support mission activities.

A district-level Climate Change Action Plan (DCCAP) needs to be formulated for all 38 districts of Tamil Nadu. Coastal districts such as Tiruvarur, Nagapattinam, Chennai, Tiruvallur, Cuddalore, and Chengalpattu are particularly at high risk in the future (2021-2050), based on a climate risk assessment using multiple indicators.

Adaptation action mapping has been carried out for vulnerable coastal stretches based on the IPCC framework, with existing and recommended actions sorted and prioritized for the coastal districts of Tamil Nadu. Further detailed field assessment and continuous monitoring are needed at the block level to address dynamic coastal risks.

The next phase includes analyzing climate change projections and sectoral risks at the block level, ground-truth verification of critically eroding coastal stretches, identifying causes of erosion, suggesting nature-based shore protection interventions, and evaluating ecological impacts of sea level rise inundation. Coastal inundation estimates will be further analyzed with high-resolution Digital Elevation Models for accuracy.

Moreover, it is essential to address limitations of the study in the district-level climate action plan. This includes analyzing Climate Change Projections and Sectoral risks at Block level, Ground truth verification of the critically eroding coastal stretches, Identifying the causes for the critical erosions and suggesting nature-based shore protection interventions, and Evaluating the ecological impacts of inundation due to Sea Level Rise. High-resolution DEM analysis will also be conducted for accurate Coastal Inundation assessments.

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Annexure

Field Photographs (DGPS Survey) at Various Coastal Districts of Tamil Nadu

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Vision

The CCCDM to be the Centre for Excellence to address challenges of Climate Change and Disaster Management

Mission

CCCDM shall contribute to the sustainable development by

- Promoting climate science and disaster risk reduction research
- Disseminating Knowledge of regional climate risks and cadastral level climate resilient actions to cope up with changing climate
- Strengthening the capacity for climate change adaptation, mitigation and disaster risk reduction

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