ATLAS OF MANGROVE WETLANDS OF ANDHRA PRADESH

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MESSAGE

The east-coast of India, particularly the Bay of Bengal region, is highly susceptible to climate change-induced disasters such as cyclones and sea level rise. Andhra Pradesh, with its extensive 1,053 km coastline (previously estimated at 974 km), is among the most disaster-prone states in the country. The low-lying coastal stretch from Srikakulam in the north to Tada in the south is vulnerable to tropical cyclones, storm surges, and flooding, leading to severe human, economic, and ecological impacts.

The region's high population density and reliance on natural resources like fisheries, agriculture, and aquaculture for livelihoods further aggravates its vulnerability. This combination of geographical exposure, socioeconomic dependency, and climate change has exacerbated the risks faced by Andhra Pradesh's coastal communities.

Major cyclones in recent years such the cyclone Hudhud in 2014 caused extensive damage in Visakhapatnam and Srikakulam, resulting in losses exceeding ₹21,000 crores and affecting over 20 million people. Cyclone Titli in 2018 brought heavy rainfall, landslides, and crop destruction in Srikakulam. In 2020, Cyclone Nivar led to torrential rains and flooding in the southern districts of Nellore and Chittoor.

To mitigate these risks, the Government of Andhra Pradesh has launched the Green Wall Mission, a coastal protection initiative aimed at reducing vulnerability to sea level rise, shoreline erosion, cyclones, and tsunamis. This mission involves the collaborative efforts of communities, government agencies, corporate sectors, and non-governmental organizations. It focuses on establishing site-specific plantations—such as mangroves and multi-species shelterbelts to enhance the ecological and economic benefits. These coastal forests also serve as valuable carbon sinks, contributing to long-term climate mitigation and adaptation.

The *Mangrove Atlas of Andhra Pradesh*, jointly published by the M.S. Swaminathan Research Foundation and the Andhra Pradesh Forest Department, provides crucial documentation of successful mangrove restoration efforts. This timely publication serves as a valuable tool for planning and implementing future projects in mangrove wetlands. I commend the team for their efforts and look forward to more such publications that continue to assess the status of our natural resources in the future.

(KONIDALA PAWAN KALYAN)

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MESSAGE

The state of Andhra Pradesh, with its extensive coastline spanning over 1,053 kilometers, is highly vulnerable to climate-related disasters such as cyclones, storm surges, and sea level rise. These events pose significant threats to the lives and livelihoods of coastal communities. To address these challenges, the Department of Environment, Forests, Science, and Technology (EFS&T), Government of Andhra Pradesh, is playing a pivotal role in building a sustainable and resilient coastal future. The department adopts a comprehensive approach that integrates ecological restoration, scientific innovation, community engagement, and strong climate governance.

In collaboration with the Andhra Pradesh Forest Department, EFS&T Dept is actively implementing the Green Climate Fund (GCF)-supported project titled *Enhancing Climate Resilience of India's Coastal Communities (ECRICC)*. Executed through the United Nations Development Programme (UNDP), this initiative focuses on ecosystem restoration—particularly mangrove regeneration—and the development of climate-resilient livelihoods to bolster the adaptive capacity of vulnerable coastal populations.

Over the past three decades, the Andhra Pradesh Forest Department, in partnership with institutions like the M.S. Swaminathan Research Foundation, has made significant progress in restoring degraded mangrove ecosystems. The success of these efforts has been recognized in the latest *Forest Survey of India* report. This *Mangrove Atlas of Andhra Pradesh* stands as a testament to these achievements and reflects the department's continued commitment to coastal resilience.

I commend the authors for their outstanding contribution in producing this important publication and documenting the valuable progress made in mangrove conservation efforts in Andhra Pradesh.

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MESSAGE

Andhra Pradesh, situated along the eastern coast of India, possesses one of the country's longest coastlines, extending over 1,053 kilometers. This coastal zone is home to some of India's most significant and ecologically sensitive mangrove ecosystems, particularly in the Krishna and Godavari estuaries. Given the region's vulnerability to cyclones and other natural disasters, these mangroves act as vital coastal bio-shields. Their intricate root systems help stabilize shorelines, trap sediments, mitigate wave impacts, and prevent soil erosion. Additionally, these ecosystems support the livelihoods of numerous small-scale fishermen.

In recent decades, the mangrove cover in Andhra Pradesh, especially in the Krishna wetlands, has seen a notable increase, thanks to sustained efforts in restoration and conservation by both national and international agencies. The Andhra Pradesh Forest Department (APFD), in collaboration with the M.S. Swaminathan Research Foundation (MSSRF), has been instrumental in reviving degraded mangrove ecosystems over the last thirty years. This partnership has focused on training and capacity building, establishing a mangrove genetic garden, and equipping field staff with restoration techniques.

The Mangrove Atlas of Andhra Pradesh captures the changes in mangrove cover over the past three decades and will serve as a valuable resource for future planning and monitoring of wetland ecosystems. I sincerely hope that this meaningful collaboration continues to thrive in the years ahead.

(AJAYA KUMAR NAIK)

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Message

Andhra Pradesh, situated along the eastern coast of India, is blessed with a diverse range of wetland ecosystems, including rivers, lakes, estuaries, lagoons, and mangrove wetlands. These ecosystems are ecologically significant and support a wide range of plants and animals making the state a vital region for biodiversity conservation in India. Mangroves are unique coastal vegetation that thrives in the intertidal and brackish water environments. They form dense forests along the coastline, particularly in river deltas. In Andhra Pradesh, mangroves are found in the estuaries of which the Godavari and Krishna are in large extent. Five thousand seven hundred forty-five species have been recorded, comprising 23% flora and 77% fauna in the Indian Mangroves. These mangrove forests are characterized by species such as *Avicennia marina* (తెల్లమడ), *Rhizophora mucronata*(అడవి పొన్న), *Sonneratia apetala* (కలింగ), and *Excoecaria agallocha* (తిల్ల), which are adapted to survive in salty, waterlogged conditions. The mangrove wetlands of Andhra Pradesh harbours the top carnivores, smooth coated otter (*Lutrogale perspicillata*) and Fishing cat (*Prionailurus viverrinus*) in sizable population. The wetlands are important habitat for the avifauna. The mangrove wetlands attract thousands of birds every year, making them crucial habitats for bird conservation. In Godavari mangrove wetland, 236 avifaunal species including 88 migratory birds feed and breed as it is located along the Central Asian Flyway. Some of the prominent bird species found in these wetlands include the spot-billed pelican, painted stork, black-headed ibis, flamingos, egrets, herons, and ducks. It is important to conserve the mangrove wetlands as they provide enormous ecosystem services to the coastal community.

The Mangrove Atlas of Andhra Pradesh has brought out the biodiversity of the mangrove wetlands along with the changes in the spatial distribution and is an important document to assess the status in future.

(Dr. S.S.Sreedhar)

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Dr. Soumya Swaminathan
Chairperson

FOREWORD

Mangroves, the unique intertidal forests found along tropical and subtropical coastlines, play a critical role in maintaining ecological balance and supporting coastal livelihoods. However, rapid urbanization, industrialization, and human pressure have led to their widespread degradation. Prof M S Swaminathan delivered a lecture in Tokyo in 1989 on anticipatory research to meet the challenge of sea level rise, pointing out the need for immediate action to conserve mangrove wetlands and for initiating research on the identification and transfer of genes for salinity tolerance from mangrove species to rice and other crops of importance. M.S. Swaminathan Research Foundation (MSSRF) organised an International Training Programme on Conservation of Mangrove Genetic Resources in which Twelve participants from 12 countries participated. A training Manual on Conservation of Mangrove Forest Genetic Resources was brought out. A team of scientists and the forest officials participated in a travelling workshop to 23 mangrove sites from 9 countries. The team selected four important Mangrove Genetic Resources Conservation centres (MGRCC) sites namely Baimuru in Papau New Guiena, Bhitarkanika in India, Sandakan from Malaysia and Mouanko in Cameroon. MSSRF was the first to transfer the saline tolerant genes from mangroves to rice through recombinant DNA technology.

MSSRF under the visionary leadership of Prof. M.S. Swaminathan, introduced the innovative concept of Joint Mangrove Management (JMM) to restore degraded areas and conserve them through participatory approaches. JMM model has been successfully implemented in the coastal areas of Andhra Pradesh, Tamil Nadu and Odisha and 2,500 ha of degraded mangroves have been restored. The state forest department provided valuable support to our efforts. In the Coringa Wildlife Sanctuary our scientists jointly with the forest officials have successfully established mangrove genetic garden with twenty-five mangrove species. The collaboration between MSSRF and APFD over three decades brought out many publications which helped the stakeholders to understand the wetlands better. Andhra Pradesh is showing continuous increase in the mangrove cover from 333 km^2 in 2001 to 421 km^2 in 2023 due to mangrove restoration and protection. The Atlas of Mangrove wetlands of Andhra Pradesh provide detailed information on the mangrove wetlands of the state, and provide a baseline for future work.

I congratulate Dr. Shanti Priya Pandey IFS Additional Principal Chief Conservator of Forests, Govt. of Andhra Pradesh, Dr. R. Ramasubramanian, Dr. R. Nagarajan, Mr. S. Niklesh, and Ms. G. Preethi of our Foundation for bringing out this publication which could be used as a reference to the status of the mangroves over three decades in Andhra Pradesh. I hope that this joint work can be a model for other states to follow.

Soumya Swaminathan

Soumya Swaminathan


2020

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We extend our heartfelt gratitude to Bharat Ratna awardee (Late) **Prof. M.S. Swaminathan**, Founder Chairman of the M.S. Swaminathan Research Foundation (MSSRF), for his visionary contributions to the conservation and management of Indian mangroves. His guidance laid a strong foundation for our continued work in this field. We also sincerely thank the Hon'ble Deputy Chief Minister for Environment, Forest, Science & Technology, Panchayati Raj, Rural Development & Rural Water Supply, **Sri Konidala Pawan Kalyan** garu, for his support and encouragement. We are also grateful to **Sri G. Anantha Ramu, IAS,** Special Chief Secretary to the Government, EFS&T; **Ajaya Kumar Naik, IFS,** Principal Chief Conservator of Forests & Head of Forest Force; **Dr. S.S. Sreedhar, IFS** (Vig. & Admn.), Principal Chief Conservator of Forests (Wildlife) and Chief Wildlife Warden (FAC) and **Dr. P.V. Chalapathi Rao, IFS,** Principal Chief Conservator of Forests Managing Director, APEMCL and AP Climate Change Cell (In-charge) for their invaluable support in the preparation of this atlas.

The Authors from MSSRF extend deep appreciation to **Dr. Soumya Swaminathan,** Chairperson of MSSRF, for her unwavering leadership and support, and to **Dr. Mathura Swaminathan,** Former Chairperson, for her encouragement and guidance.

The team from MSSRF also thank **Dr. G.N. Hariharan,** former Executive Director – R&D, and **Dr. R. Rengalakshmi,** Executive Director – Area Operations, MSSRF, for their ongoing motivation and support. Special thanks to our colleagues **Ms. S. Punitha, Dr. R. Murugan, Dr. M. Utchimahali, Dr. S. Sravani, Mr. G. Vishnu Ram, Mr. N. Babji, Mr. D. Srinivasa Rao,** and **Mr. B. Augustine,** for their dedicated efforts in preparing this atlas.

The MSSRF team are grateful to the officials of the Andhra Pradesh Forest Department for their valuable cooperation during field surveys and for providing essential ground-truth data.

CONTENTS

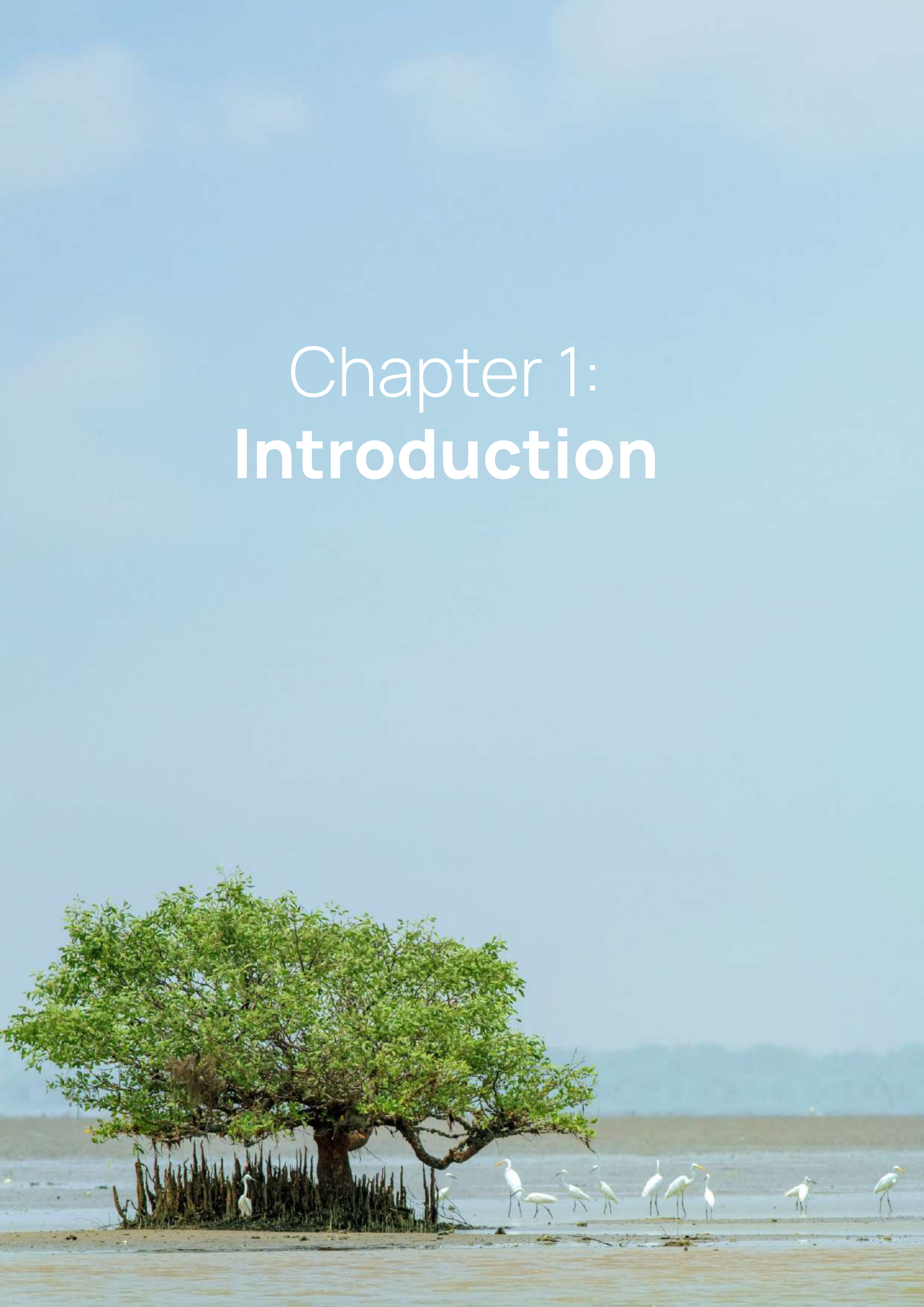
List of Tables

List of Figures

List of Abbreviations

APFD	Andhra Pradesh Forest Department
CITES	Convention on International Trade in Endangered Species
CR	Critically Endangered
DRDO	Defence Research and Development Organisation
DSAS	Digital Shoreline Analysis System
EN	Endangered
EPR	End Point Rate
GMW	Global Mangrove Watch
IRS	Indian Remote Sensing
ISFR	Indian State Forest Report
IUCN	International Union for Conservation of Nature
JMM	Joint Mangrove Management
km	Kilometre
LISS IV	Linear Imaging Self Scanning Sensor IV
LRR	Linear Regression Rate
LULC	Land Use and Land Cover
MGRCC	Mangrove Genetic Resources Conservation Centre
MSSRF	M. S. Swaminathan Research Foundation
MT	Metric Tonnes
NDVI	Normalised Difference Vegetation Index
NSM	Net Shoreline Movement
ppt	Parts Per Thousand
RAI	Relative Abundance Index
RF	Reserve Forest
RLE	Red List of Ecosystems
SDG	Sustainable Development Goals
UN	United Nations
USA	United States of America

Chapter 1: **Introduction**



Chapter 1: Introduction

Mangrove wetlands are unique coastal ecosystems characterised by salt-tolerant trees and shrubs typically found in the tropical and subtropical coastlines, especially in estuarine areas where the water is saline. Mangrove ecosystems are one of the important natural resources that offer both ecological and economic benefits to coastal communities. Mangrove ecosystems occur on approximately 75% of the world's tropical coastlines, between 25°N and 25°S. However, the extent of mangroves extends beyond these areas due to the movement of warm waters from the equator, as seen on the east coast of Africa, Australia, and New Zealand, where mangrove wetlands are found between 10° and 15° farther south. Similarly, in Japan, Florida, Bermuda, and the Red Sea, mangroves extend between 5° and 7° farther North. Mangrove plants possess structural adaptations, such as prop roots, pneumatophores, and knee roots, as well as buttressed stems, which allow them to survive in waterlogged, anoxic soils. These adaptations anchor them firmly in muddy, waterlogged, saline soils. Another notable feature of a few mangrove plants, particularly in the Rhizophoraceae and Acanthaceae families, is vivipary, where seeds germinate while still attached to the parent plant. Some mangrove species prevent salt from entering their roots, while others excrete salt through specialised glands.

Mangrove ecosystems support biodiversity, with 341 threatened species that rely on these habitats. They support the livelihoods of 4.1 million small-scale fishers globally. Mangrove ecosystems reduce disaster risks effectively than artificial barriers in dissipating wave energy, trapping sediment, reducing erosion, and stabilising shorelines (Schoonees et al., 2019; Karimi et al., 2022). The mangrove forests and certain other coastal vegetation can significantly mitigate the impact of tsunamis on coastlines (Hiraishi, 2003). Few analytical models suggest that a density of 30 trees per 100 m² in a 100-meter-wide belt could reduce tsunami waves up to 90% (Hiraishi and Harada 2003), suggesting that these coastal bioshields are both sustainable and more cost-effective compared to artificial barriers such as sea walls and groins (Hiraishi and Koike 2001; Hiraishi 2003). Mazda et al. (1997) observed the effectiveness of mangrove forests in coastal protection in Vietnam. Kelty et al. (2021) demonstrated that dense and healthy mangrove forests can significantly mitigate the impacts of tsunamis. The dense aboveground mangrove canopy and robust root structure influence wave attenuation, slowing water flow and dissipating wave energy (Gijsman et al., 2021). Studies proved that mangroves can attenuate wind and swell waves under 70 cm in height by 50% to 99% across a 500-meter-wide mangrove forest (Quartel et al., 2007; Vo-Luong and Massel, 2008; Bao, 2011). The *Rhizophora* mangrove forests reduced the impacts of hurricanes by up to 24% where the mangrove forests were less than 1 km wide, while more extensive mangrove areas were relatively unaffected (Del Valle et al., 2020). Several factors affect wave height as waves pass through mangroves, including water depth, wave height, mangrove species, tree age and size (McIvor et al., 2012). The surface waves travelling through a mangrove forest experience significant energy loss due to two primary dissipation mechanisms: multiple interactions with mangrove trunks and roots, and bottom friction. Projected sea level rise (0.26 m to 0.98 m by 2100) is likely to aggravate storm impacts by accelerating flooding in the low-lying areas (Jones et al., 2021). However, mangrove ecosystems can trap sediments and grow vertically reducing the effects of rising sea levels. Given the right sediment type, Chow (2018) noted that mangroves can proliferate and mitigate the impacts of sea level rise. Alongi (2008) observed that mangroves can keep pace with the rising sea level by sedimentation relative to the increase in sea level. Economically, mangroves mitigate storm damage, averting over $65 billion in property losses and reducing flood risks for approximately 15 million people annually.

Mangroves store significantly higher carbon stocks than other ecosystems, such as rainforests, peat swamps, salt marshes, and seagrasses. Mangrove forests store carbon between 140 and 1023 Mg C ha^{-1} (Donato et al., 2011; Alongi, 2014; Schile et al., 2017). These global statistics indicate that mangroves store an average of 394 tonnes of carbon per hectare. Of this total, 319 tonnes are held in the soil, 54 tonnes in aboveground biomass, and 21 tonnes in belowground biomass. The highest carbon densities in mangroves are found in Southeast Asia, particularly in the Philippines. In some regions of the Philippines, carbon densities exceed 650 tonnes per hectare, whereas the Middle East has the lowest carbon density, with less than 100 tonnes per hectare (Bunting et al., 2022). Mangroves also filter pollutants and nutrients from the river runoff, enhancing water quality and supporting adjacent marine productivity, including fisheries.

1.1. Mangroves and UN Sustainable Development Goals (SDGs)

Mangrove ecosystems play a significant role in achieving the Sustainable Development Goals (SDGs), particularly those related to climate action and biodiversity conservation. Mangroves contribute to mitigating climate change (SDG 13) as they are efficient in sequestering carbon dioxide, storing up to four times more carbon than tropical forests. Mangrove ecosystems capture and store carbon equivalent to over 21 billion tons of CO_2. They act as natural barriers against storm surges and rising sea levels, reducing the impact of climate-related disasters on coastal communities. Mangroves support a diverse array of marine and terrestrial species, providing habitats for fish, birds, and other wildlife. They serve as an important nursery ground for many commercially important fish species, thereby contributing to SDG 14: Life Below Water. They also improve water quality by trapping sediments and absorbing pollutants and nutrients. Mangroves contribute to SDG 15: Life on Land by maintaining the health of adjacent terrestrial and freshwater ecosystems. They protect various species, including endangered and threatened ones, thus playing a role in preserving biodiversity. Apart from these SDGs, the mangrove ecosystems support SDG 1: No Poverty, as coastal communities depend on mangroves for their livelihoods, including fishing, tourism, and harvesting resources such as honey and medicinal plants. It also

supports SDG 2: Zero Hunger, as the mangrove ecosystem supports fisheries, an essential source of protein. Healthy mangrove ecosystems improve fish stocks. The mangrove ecosystems also contribute to SDG 6: Clean Water and Sanitation, as they filter pollutants and enhance the quality of water, thereby benefiting both marine life and human populations that rely on clean water sources.

1.2. Global Distribution of Mangroves

The mangrove wetlands of Sundarbans in India and Bangladesh together form one of the largest continuous mangrove ecosystems in the world. According to the Global Forest Resource Assessment (2020), the global mangrove area spans approximately 14.76 million hectares. The coastal regions of Asian countries contribute 5.55 million hectares. In 2022, the Global Mangrove Watch (GMW) updated its global mangrove distribution map. It estimated about 14.74 million hectares of mangroves in 2020, showing an increase of 1.1 million hectares from the previous estimation carried out in 2016 (Table 1). This expansion primarily reflects improved mapping techniques rather than actual growth in mangrove extent. The minor mangrove wetlands, previously unaccounted in countries such as Bangladesh, Benin, Colombia, Fiji, India, Indonesia, Nigeria, and the USA, were incorporated. Southeast Asia harbours the most significant extent of mangroves, with Indonesia alone contributing one-fifth of the global total. Indonesia, Brazil, Australia, Mexico, and Nigeria account for nearly half of the world's mangroves. Mangrove wetlands in 20 countries (Table 2) contribute almost 80% of the global mangrove area. Anthropogenic activities are estimated to account for 62% of total mangrove losses. The loss of mangroves between 2010 and 2020 was estimated at 600 km^2, with direct human impacts accounting for approximately 373 km^2 of this loss. Valderrábano et al. (2024) classified global mangrove ecosystems using the IUCN Red List of Ecosystems (RLE) methodology. They found that 18 mangrove provinces, accounting for approximately 50% of the world wide mangrove area, are threatened. Among these, eight provinces are listed as either Endangered (EN) or Critically Endangered (CR).

Table 1: Region-wise Mangrove cover across the globe

S.No	Region	Area in km²	Percentage
1	Southeast Asia	48,222	32.72
2	South Asia	9,549	6.48
3	East Asia	228	0.15
4	Middle East	285	0.19
5	North & Central America & the Caribbean	22,827	15.49
6	South America	20,378	13.82
7	West & Central Africa	21,715	14.73
8	East & Southern Africa	7,630	5.18
9	Australia & New Zealand	10,467	7.10
10	Pacific Islands	6,058	4.11
	Total	**147,359**	**100**

Table 2: Top Twenty Countries in Terms of Mangrove Area

S.No	Country	Global Share (%)	Rank
1	Indonesia	19.5	1
2	Brazil	8.1	2
3	Australia	7.3	3
4	Mexico	6.9	4
5	Nigeria	5.1	5
6	Malaysia	3.8	6
7	Myanmar	3.6	7
8	Papua New Guinea	3.5	8
9	Bangladesh	3.0	9
10	India	2.9	10
11	Venezuela	2.3	11
12	Philippines	1.9	12
13	Cuba	1.9	13
14	Thailand	1.8	14
15	Mozambique	1.6	15
16	Colombia	1.5	16
17	Vietnam	1.5	17
18	Panama	1.4	18
19	Republic of Guinea-Bissau	1.2	19
20	Ecuador	1.2	20

Recently, Duke and Lee (2024) compiled a list of all mangrove taxa worldwide, comprising 82 species, including 14 hybrids, across 32 genera of 18 families. The Indo-West Pacific (IWP) is diverse, with 63 species, while the Atlantic East Pacific (AEP) has 19 species (Table 3).

Table 3: Distribution of mangrove species in the two global sub-region hotspots

S.No	Biological Classification	Indo-West Pacific (IWP)	Atlantic East Pacific (AEP)	Worldwide
1	Families	15	9	18
2	Genera	24	11	32
3	Species + hybrids	63	19	82
4	Hybrids	12	2	14
5	Species - hybrids	51	17	68
6	Sub-specific taxa	4	0	4

1.3. Mangrove wetlands in India

The extent of mangroves in India is 4,991.68 km^2 (Table 4), representing 0.15% of the nation's total land area (FSI, 2024). The Indian mangrove constitutes merely 2.9% of the global mangroves. West Bengal accounts for 42.45%, followed by Gujarat (23.66%), the Andaman and Nicobar Islands (12.39%) and Andhra Pradesh (8.44%). Major mangrove wetlands are located along the east coast, while the west coast's significant mangrove regions are primarily in Gujarat. Most rivers originate in the north and west, travelling towards the east coast, where they form large estuaries suitable for mangroves to grow (Fig. 1). The diversity and extent of mangrove wetlands in Sundarbans and Bhitarkanika are high. The diversity is less on the south-east and west coasts of India, which are influenced by factors such as estuary size, tidal water reach, sediment supply, and freshwater inflow. The assessment of mangroves, as per the Indian State Forest Report (2023), showed an increase from 4,975 to 4,992 km^2 between 2019 and 2023. Compared to the 2021 assessment, the 2023 assessment showed a slight decrease of 7.43 km^2 in the overall mangrove extent. Gujarat showed a significant reduction of 36.39 km^2, while Andhra Pradesh experienced a notable increase of 13.01 km^2, followed by Maharashtra with an increase of 12.39 km^2. The main reasons for the increase in mangrove cover in Andhra Pradesh and Maharashtra are the restoration of mangroves in degraded areas and natural mangrove regeneration in new areas. However, nearly 40.60% of the mangroves in India are categorised as open, with a canopy density of 10 to 40%. The Government of India's MISHTI program aims to enhance the open forest by transforming it into a dense mangrove cover in coastal states. The total estimated biomass of Indian mangrove forests was 41.2 million tons, while the carbon stocks in Indian mangrove forests were 20.59 million tons. The mangrove plantations sequester carbon at a mean rate of 0.47 ± 0.23 t yr^{1}, and this sequestration is species-specific. *Rhizophora mucronata, Kandelia candel* and *Avicennia marina* sequester carbon at a slower rate while *Excoecaria agallocha* and *Avicennia officinalis* accumulate faster (Suresh et al., 2017).

Table 4: State-wise distribution of Mangroves in India

S. No.	State	Total area (km^2)	Percentage
1	West Bengal	2119.16	42.45
2	Gujarat	1164.06	23.32
3	Andaman & Nicobar Islands	608.29	12.19
4	Andhra Pradesh	421.4	8.44
5	Maharashtra	315.09	6.31
6	Odisha	259.06	5.19
7	Tamil Nadu	41.91	0.84
8	Goa	31.34	0.63
9	Karnataka	14.2	0.28
10	Kerala	9.45	0.19
11	Daman & Diu	3.86	0.08
12	Puducherry	3.83	0.08
	Total	**4992**	**100.00**

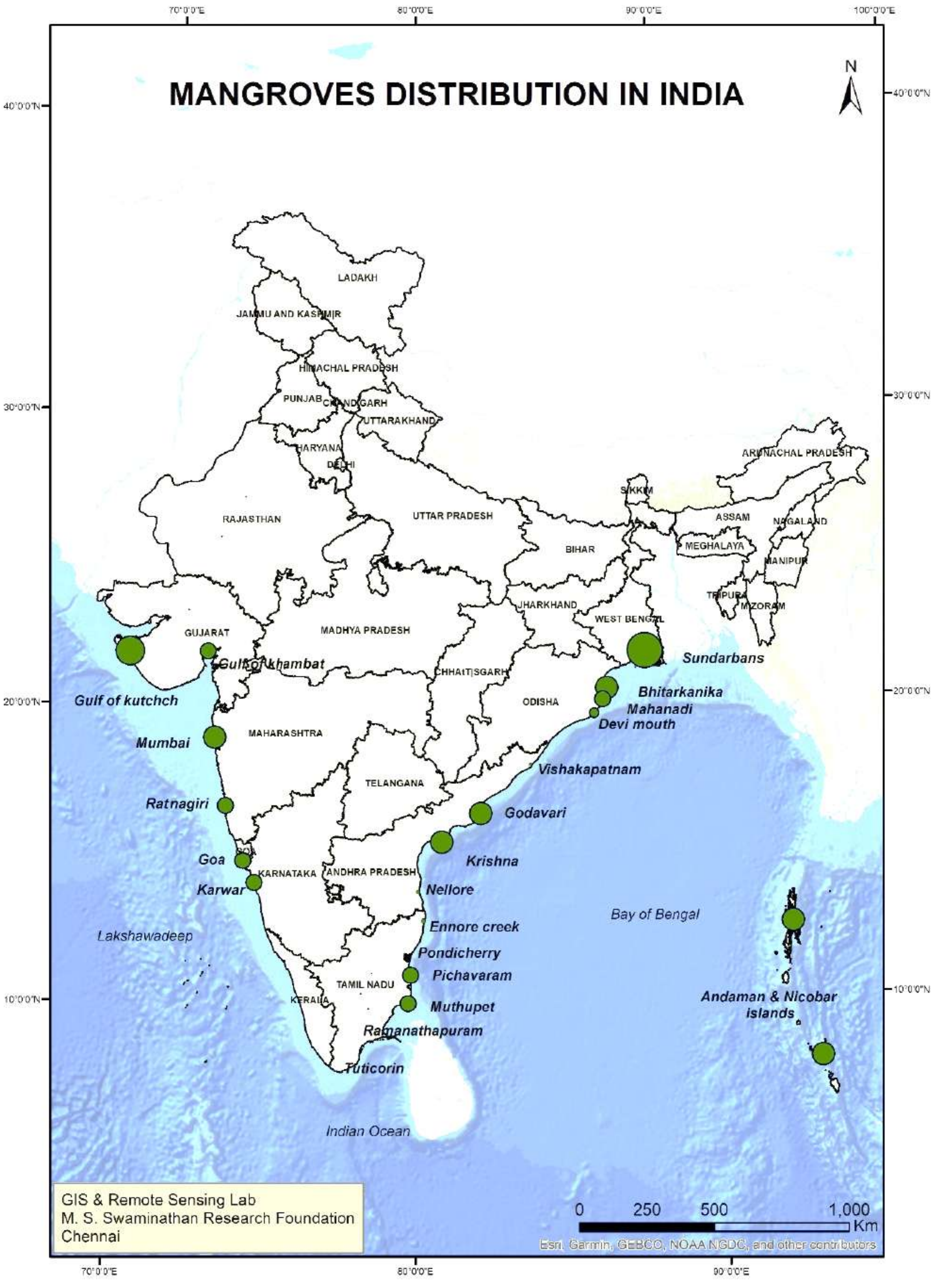
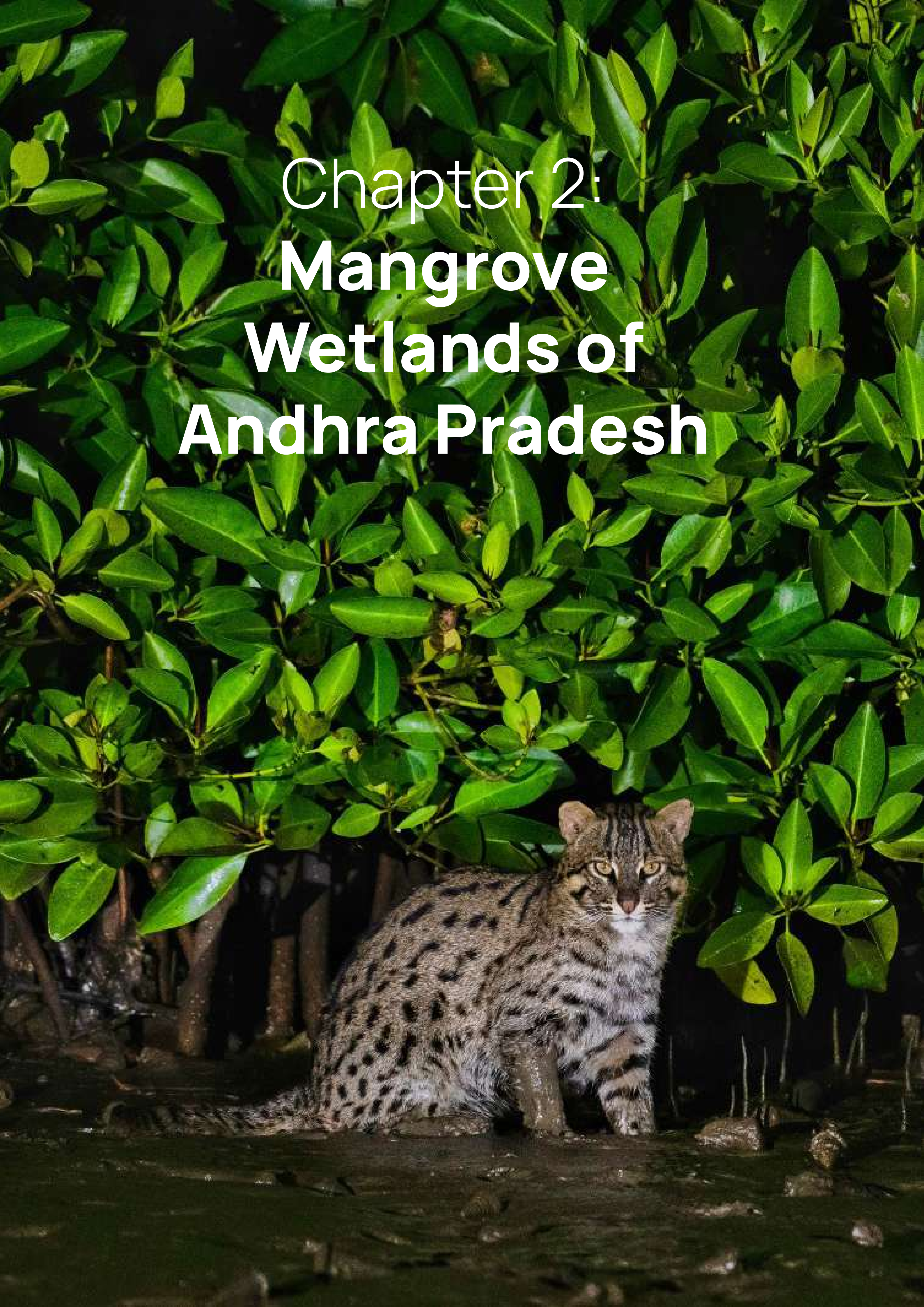


Figure 1: Distribution of Mangrove wetlands on the Indian coast

1.4. Bio-Diversity of Indian Mangroves

The mangrove flora in India is diverse, comprising 46 true mangrove species, including four natural hybrids, belonging to 22 genera across 14 families. The mangrove diversity in India, in terms of richness, is third highest, next to Indonesia and Australia, followed by Malaysia, Thailand, Philippines, Singapore, and China (Ragavan et al., 2016). India has two globally threatened species, *Heritiera fomes* and *Sonneratia griffithi*, out of a total of 11 species listed under the IUCN Red List (Kathiresan, 2010). In addition, *Excoecaria indica* and *Aglaia cucullata* are categorised as data deficient, while species such as *Aegialitis rotundifolia, Brownlowia tersa, Ceriops decandra, Phoenix paludosa*, and *Sonneratia ovata* are near threatened (Ragavan et al., 2016). Indian mangrove forests have the highest biodiversity worldwide, with no other country documenting as many species within this ecosystem. Five thousand and seven hundred forty-five species have been recorded, comprising 23% flora and 77% fauna. Eight major groups dominate the ecosystem, each exceeding 100 species: mangrove species (including both true mangroves and mangrove associates), marine algae (such as phytoplankton and seaweeds), fungi, crabs, molluscs, insects, other invertebrates, and finfish (Ragavan et al., 2016; Kathiresan, 2018; 2023). The Sundarbans is recognised as a UNESCO World Heritage Site and the only site with tigers in the mangrove wetland. The Sundarbans, a vast wetland spanning India and Bangladesh, is the largest mangrove forest in the Gangetic Delta. It provides a habitat for globally endangered fishing cats, Gangetic dolphins, estuarine crocodiles, horseshoe crabs, water monitor lizards, and river terrapins.

Chapter 2: Mangrove Wetlands of Andhra Pradesh



Chapter 2: Mangrove Wetlands of Andhra Pradesh

Andhra Pradesh is situated in the southern part of India, between 12°41' and 19.07°N and 77° and 84°40'E. It is the seventh-largest state located on the east coast of India, with an extent of 1,62,975 km^2, constituting 4.96% of India's total geographical area. The state shares its borders with Chhattisgarh to the North, Odisha to the northeast, Telangana and Karnataka to the west, Tamil Nadu to the south, and the Bay of Bengal to the east. The state's geography is divided into the coastal and the Rayalaseema regions. Andhra Pradesh has a coastline that stretches approximately 974 kilometres (recent length 1053 km). Andhra Pradesh is India's 10th most populous state. According to the Unique Identification Aadhar India, by mid-2020, the state's projected population will be about 53.9 million. In 2011, the state had a population of 49.58 million. There are 26 districts in the state, of which 12 are coastal districts. Two major rivers, the Godavari and the Krishna, and several minor rivers flow through the state, which has mangroves in the estuarine areas.

2.1. Distribution of Mangrove wetlands in Andhra Pradesh

Mangrove wetlands are found in all coastal districts except Vizianagaram. The total extent of mangroves in Andhra Pradesh is approximately 505.5 km^2, with mangroves predominantly found in the districts of Krishna, Kakinada, Bapatla, and B.R. Ambedkar Konaseema (Table 5). Besides these major mangrove wetlands, mangroves are found in Srikakulam, Visakhapatnam, Anakapalli, Prakasam, Sri Potti Sriramulu Nellore, Tirupati and Eluru districts (Fig. 2). All these mangrove areas are primarily located along estuarine areas, and coastal fringes, playing a crucial role in shoreline stabilization, biodiversity conservation, and supporting local livelihoods through fisheries.

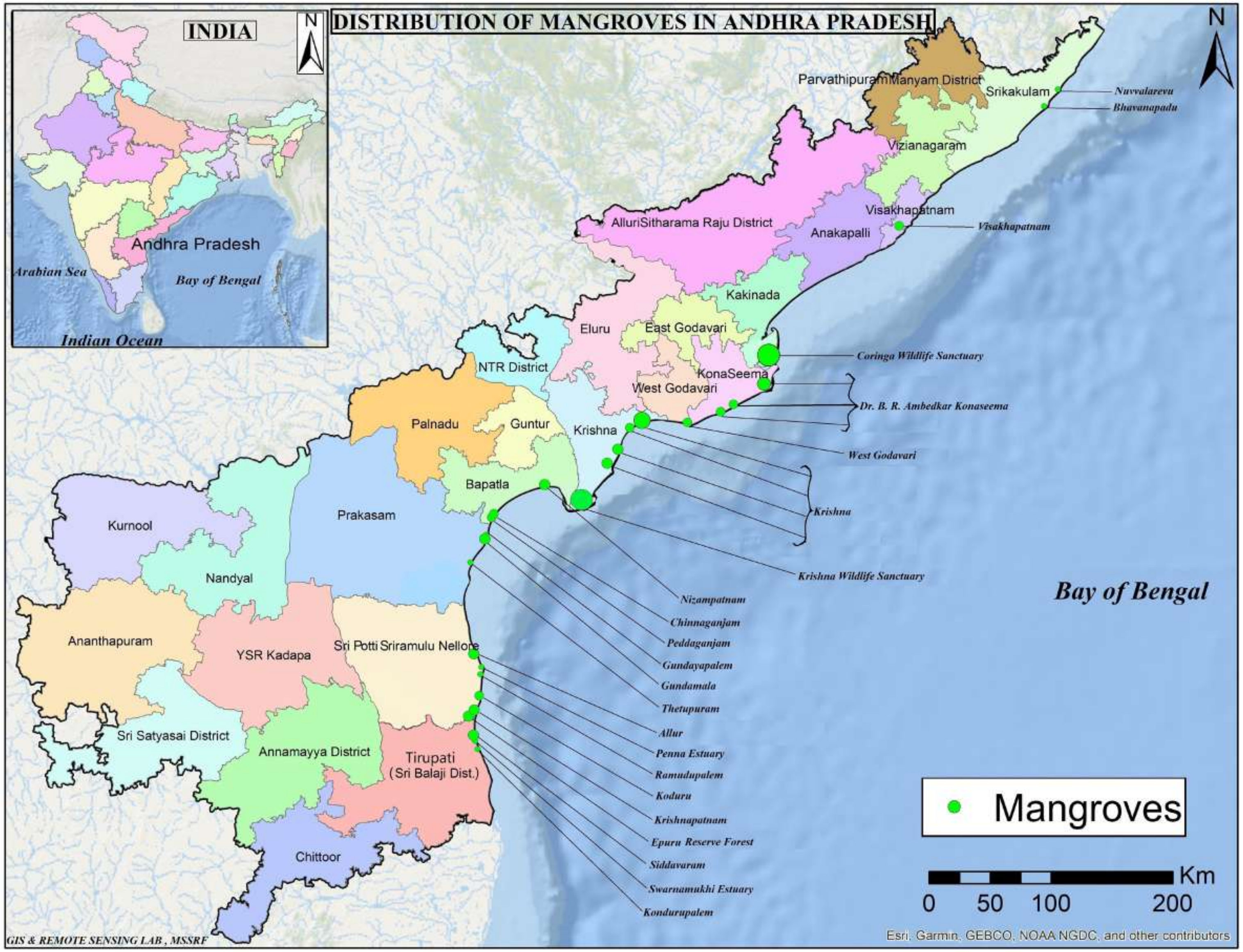


Figure 2: Distribution of Mangrove wetlands along the coast of Andhra Pradesh

Table 5: District-wise distribution of Mangroves in Andhra Pradesh (2023)

S. No.	Districts	Mangrove Cover (km^2)
1	Krishna	179.8
2	Kakinada	139.7
3	Bapatla	85.7
4	B. R. Ambedkar Konaseema	80.5
5	Sri Potti Sriramulu Nellore	10.0
6	Srikakulam	2.9
7	Prakasam	2.9
8	Eluru (West Godavari)	1.5
9	Anakapalli	1.2
10	Tirupati	0.8
11	Visakhapatnam	0.5
	Total	**505.5**

2.1.1. Mangrove wetlands in Krishna District

The distribution of mangroves in Krishna district covers an area of 179.8 km^2 (Fig. 3), with wetlands primarily located along the Krishna River delta and coastal stretches in Machilipatnam Rural, Kruthivennu, and Interu Mandals. The mangrove species diversity is rich and dominated by *Avicennia marina*. The detailed biodiversity of the Krishna Wildlife Sanctuary is discussed in Chapter 4.

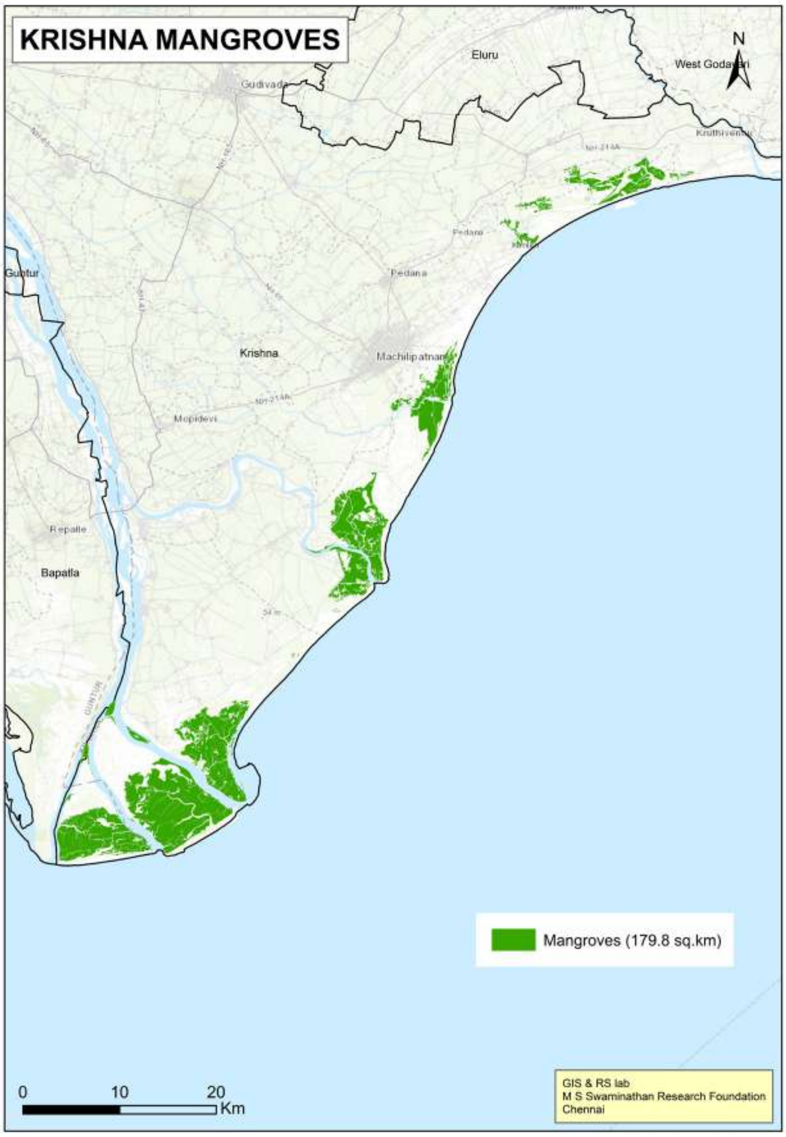


Figure 3: Mangrove wetlands in Krishna District

2.1.2. Mangrove wetlands in Kakinada District

The extent of mangroves in the Kakinada district is about 139.7 km^2 (Fig.4). These mangrove wetlands are located along the coastal stretches and estuarine areas near Kakinada Bay and the Godavari delta, including parts of the Coringa Wildlife Sanctuary. The detailed report, including the biodiversity and decadal changes in mangrove cover, is provided in Chapter 3.

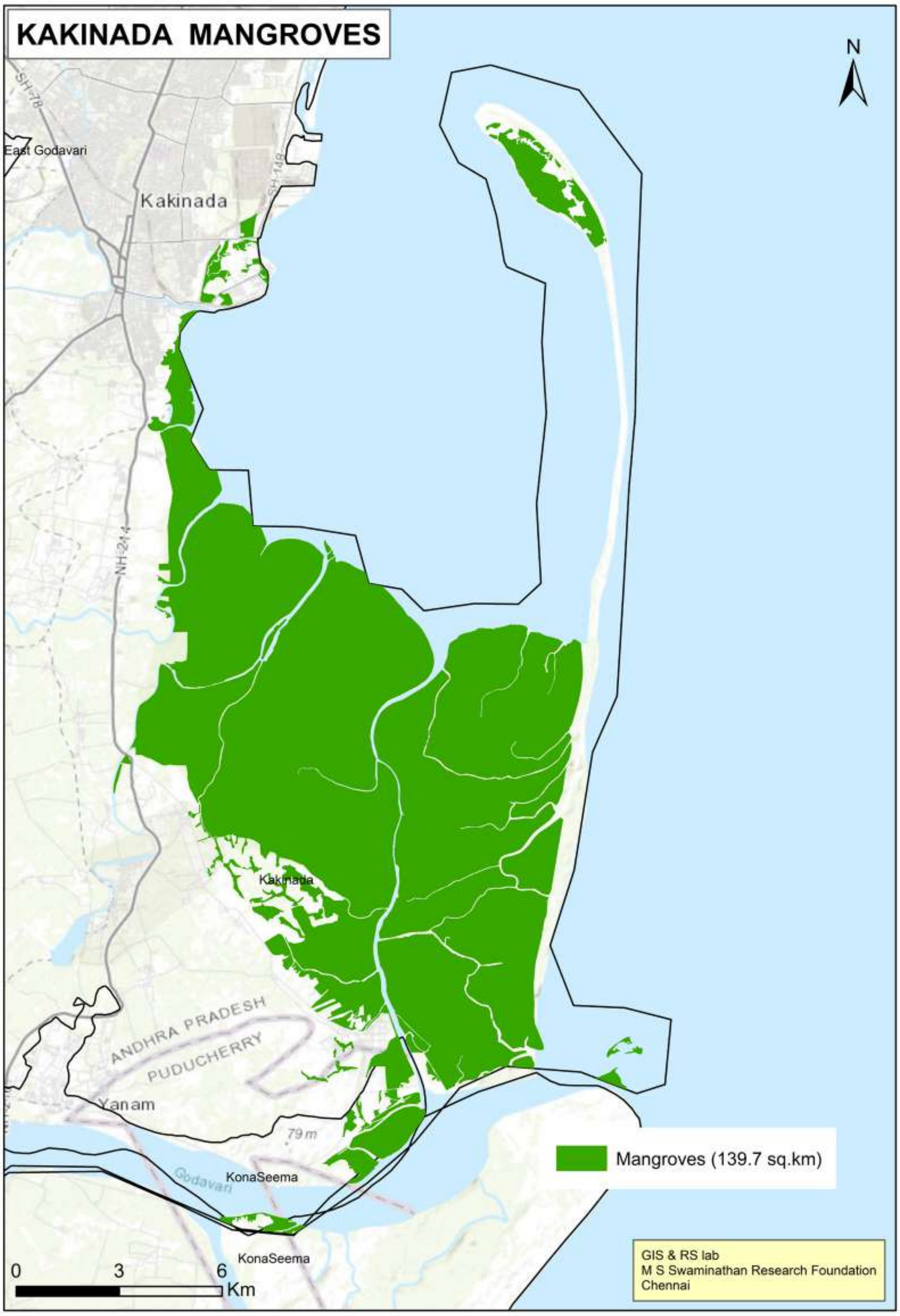


Figure 4: Mangrove wetlands in Kakinada District

2.1.3. Mangrove wetlands in Bapatla District

Mangroves in the Bapatla district cover an area of 85.7 km^2 (Fig. 5), forming an important coastal belt along the Krishna estuary in Repalle and Nizampatnam Mandals. *Avicennia marina* is the dominant species, while *Aegiceras corniculatum, A. alba, A. officinalis, Bruguiera cylindrica, B. gymnorrhiza, Ceriops decandra, Excoecaria agallocha, Lumnitzera racemosa, Rhizophora apiculata,* R. *mucronata, Xylocarpus granatum* and *Sonneratia apetala* are commonly found in the wetlands.

These mangrove forests, located in estuarine zones, backwaters, and lagoons provide shoreline protection and support a diverse array of biodiversity. The detailed biodiversity of this region is presented in chapter 4, specifically for the Krishna mangrove wetland.

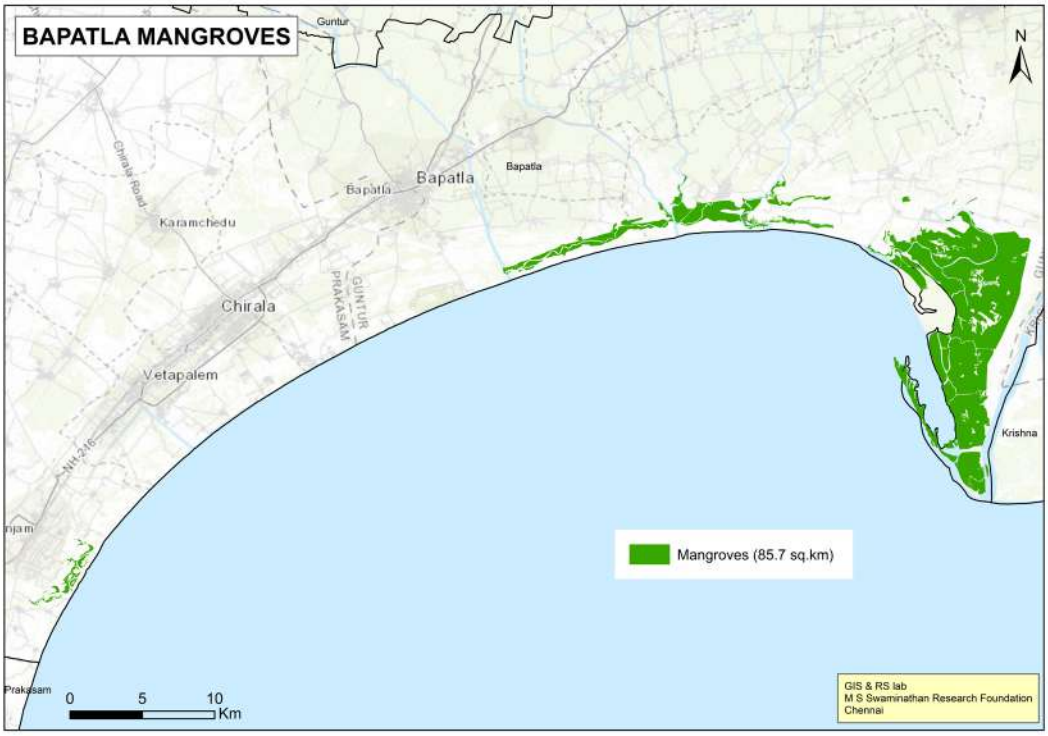


Figure 5: Mangrove wetlands in Bapatla District

2.1.4. Mangrove wetlands in B. R. Ambedkar Konaseema District

The distribution of mangroves in the Konaseema district of Andhra Pradesh, covers an area of approximately 80.5 km^2 (Fig. 6). Extensive mangrove cover is observed along the coastline near the mouth of the Godavari River in Mummidivaram and Katrenikona Mandals, and smaller patches are scattered near the estuarine regions of Vasista and Vynatheya distributaries of the Godavari River. The detailed biophysical and decadal changes in mangrove cover are given in Chapter 3.

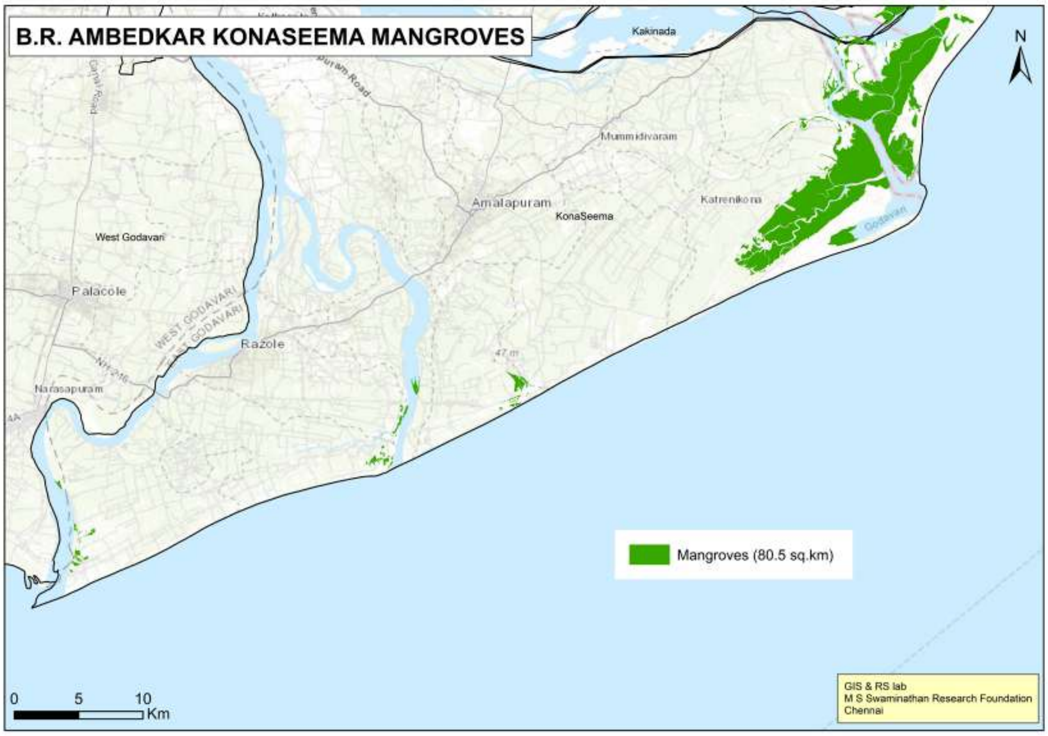


Figure 6: Mangrove wetlands in B. R. Ambedkar Konaseema District

2.1.5. Mangrove wetlands in Sri Potti Sriramulu Nellore District

The mangrove cover in the Sripotti Sriramalu Nellore district is about 10 km² (Fig. 7). Mangrove wetlands occur mainly along Kandaleru Creek, backwaters near Krishnapatnam, Momidi, and in the estuarine regions of Swarnamukhi backwaters. Iskapalli Lagoon, located in the Pennar Delta, receives inflow from the Pyderu River and is home to a unique mangrove flora and salt pans. A thin population of *Kandelia candel* was reported in Iskapalli Lagoon (Rao and Ramasubramanian, 2013). The list of true mangroves occurring in the wetlands of the district is given in Table 6.

Table 6: Mangrove species in Sri Potti Sriramulu Nellore District

S. No.	Species	Family
1	*Acanthus ilicifolius* L.	Acanthaceae
2	*Aegiceras corniculatum* (L.) Blanco	Myrsinaceae
3	*Avicennia marina* (Forsk.) Vierh	Acanthaceae
4	*Avicennia officinalis* L.	Acanthaceae
5	*Bruguiera cylindrica* (L.) Blume.	Rhizophoraceae
6	*Bruguiera gymnorrhiza* (L.) Savigny	Rhizophoraceae
7	*Ceriops decandra* (Griff.) Ding Hou	Rhizophoraceae
8	*Kandelia candel* (L.) Druce	Rhizophoraceae

S. No.	Species	Family
9	*Lumnitzera racemosa* Wild.	Combretaceae
10	*Rhizophora apiculata* Bl.	Rhizophoraceae
11	*Rhizophora mucronata* Lamk.	Rhizophoraceae
12	*Excoecaria agallocha* L.	Euphorbiaceae
13	*Sonneratia apetala* Buch.-Ham.	Lythraceae

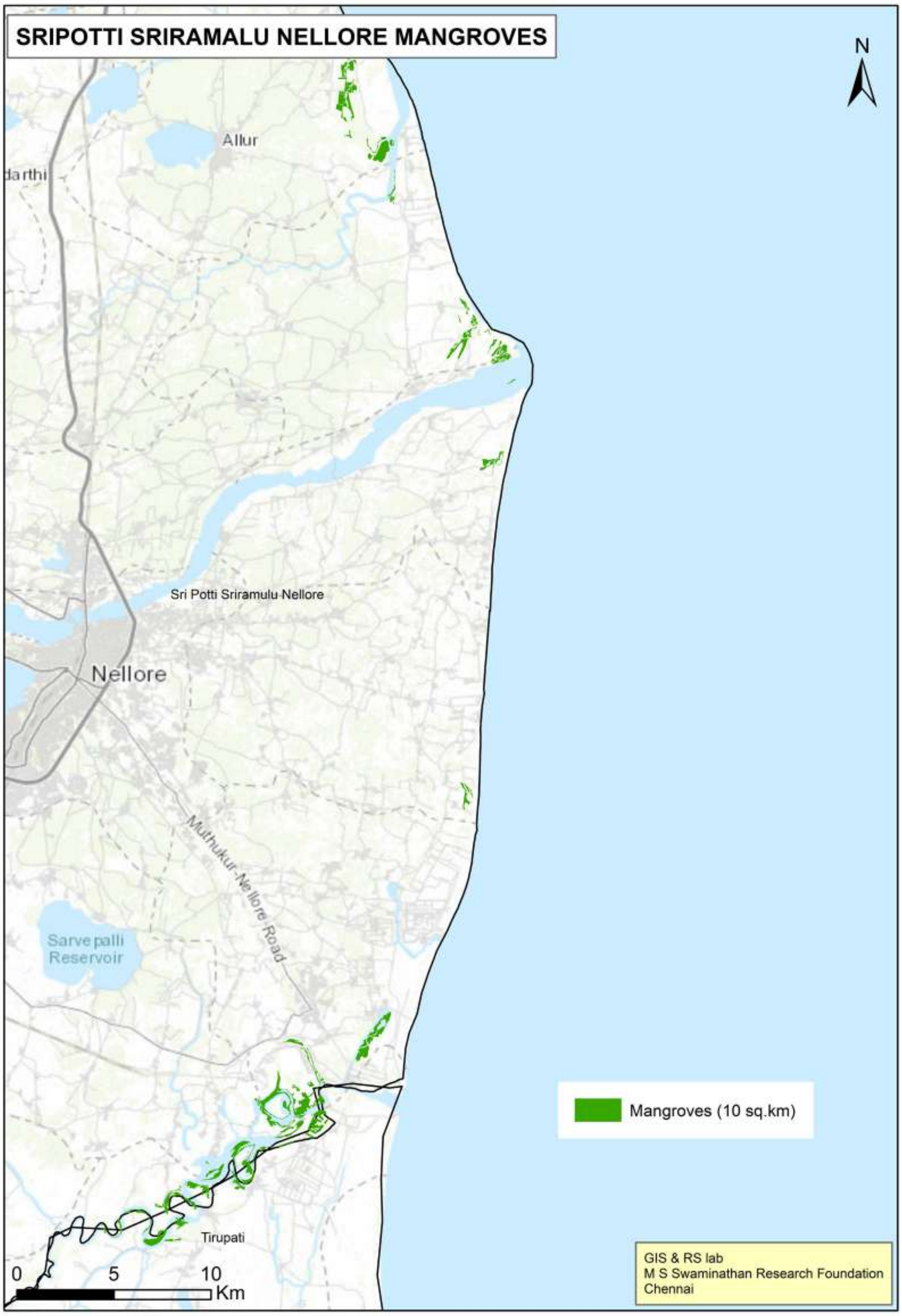


Figure 7: Mangrove wetlands in Sri Potti Sriramulu Nellore District

2.1.6. Mangrove wetlands in Srikakulam District

Mangrove cover in Srikakulam district is approximately 2.9 km^2 (Fig. 8), primarily located in the Nuvvalarevu and Bhavanapadu wetlands. In Nuvvalarevu, the dominant species is *Avicennia marina*, while *Acanthus ilicifolius* is the least distributed. Other associated halophytes include *Aeluropus lagopoides, Cressa cretica, Heliotropium curassavicum, Salicornia brachiata, Sesuvium portulacastrum*, and *Suaeda maritima*. In Bhavanapadu, *Avicennia marina* is predominant, with *Bruguiera cylindrica, Ceriops decandra*, and *Sonneratia apetala* being less common. Near Mulapet village *A. marina*, is dominant, accompanied by associated halophytes such as *Sesuvium portulacastrum* and *Suaeda maritima*.

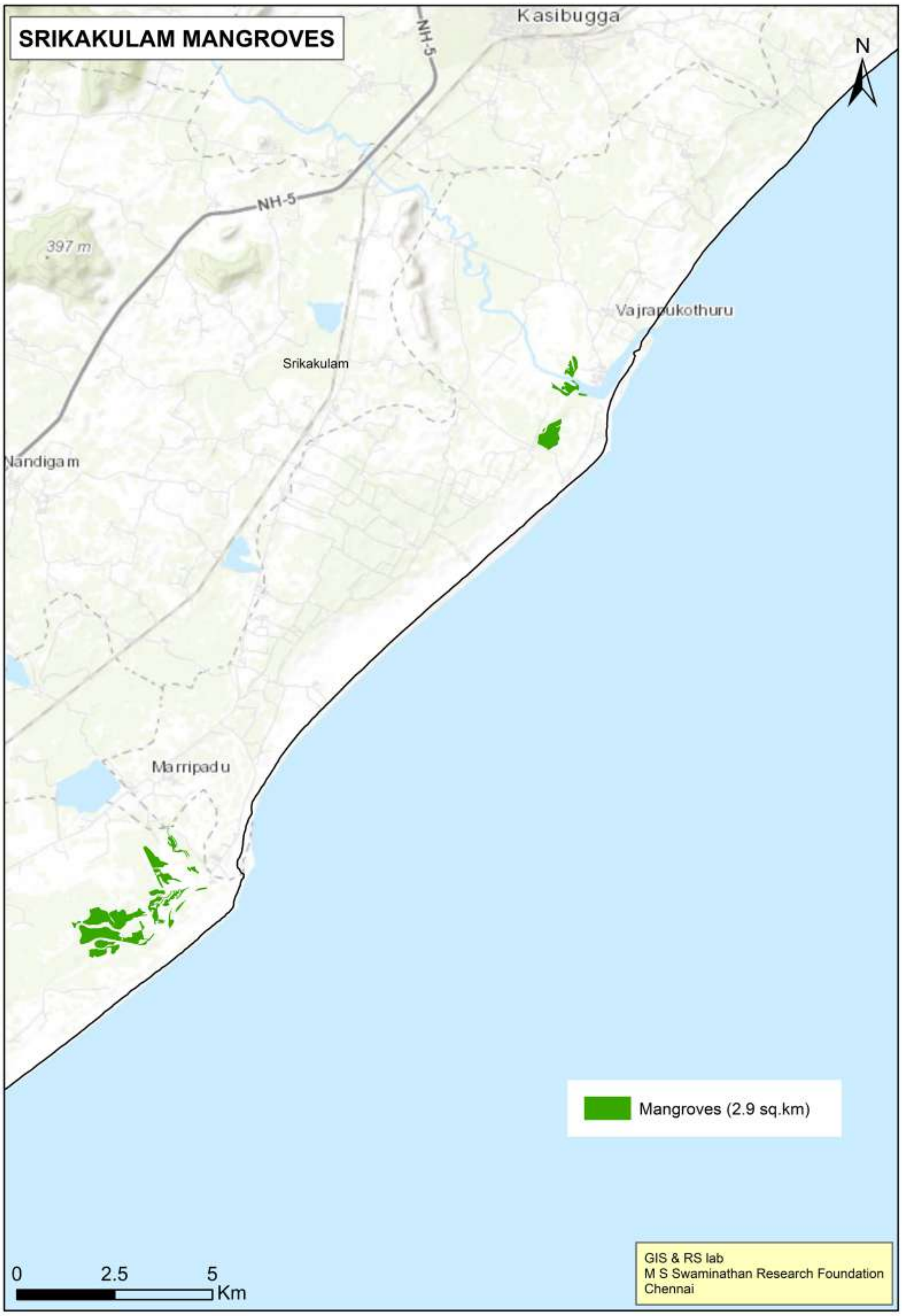


Figure 8: Mangrove wetlands in Srikakulam District

2.1.7. Mangrove wetlands in Prakasam District

In Prakasam district, the total mangrove area spans approximately 3 km^2 (Fig. 9). The Prakasam district is home to the Gundlakamma River which flows for a length of 220 km. There are other streams, such as the Musi, Paleru, Maneru, Romperu drain, Tammileru, Sagileru, and Gudisaleru, as well as minor streams like Vaguru Vagu, Nallavagu, and Vedimangala Vagu, that flows through the district. The key mangrove patches are found in the Romperu drain, Musi-Paleru estuary, and Gundlakamma estuary. *Avicennia marina, Rhizophora mucronata, Excoecaria agallocha* and *Aegiceras corniculatum* are the major mangroves present in this district.

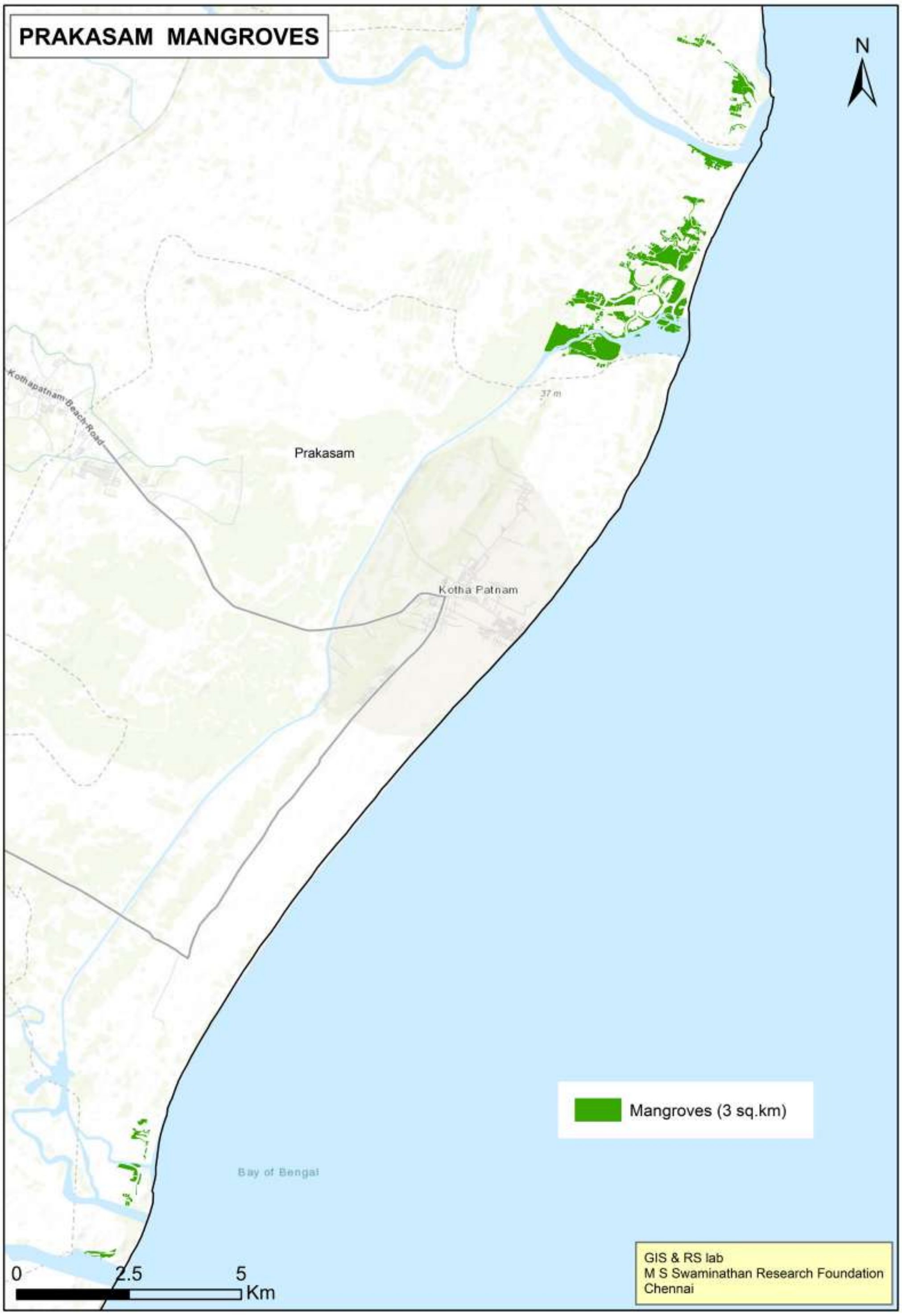


Figure 9: Mangrove wetlands in Prakasam District

2.1.8. Mangrove wetlands in Eluru (West Godavari) District

The extent of mangroves in Eluru District spans approximately 1.5 km^2 (Fig. 10) and is primarily concentrated along the southern coastal and estuarine regions. Most of the mangroves are found along the Godavari estuary and in the abandoned shrimp farms. *Avicennia marina* is the dominant species, with thickets of *Acanthus ilicifolius* found along the bunds.

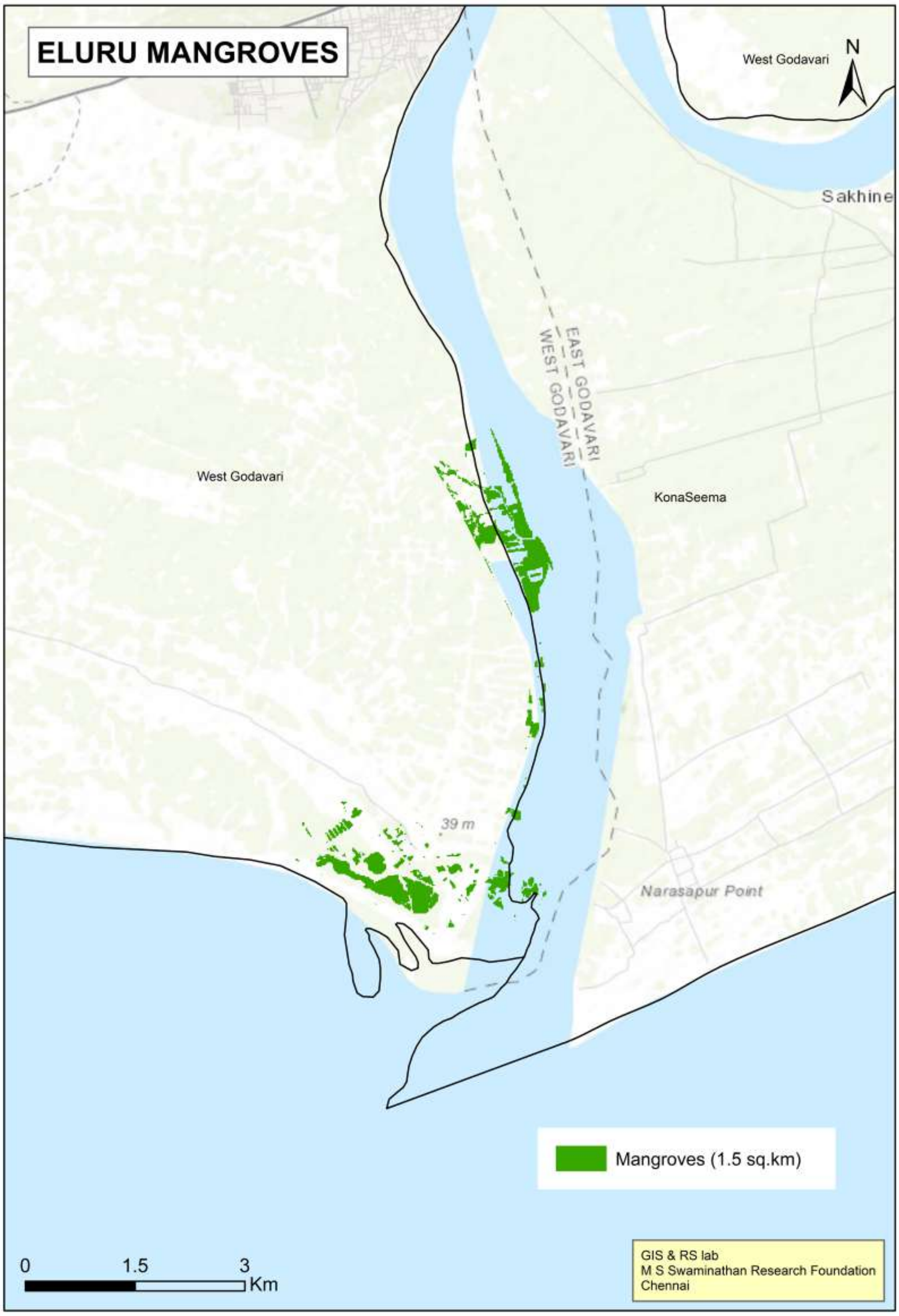


Figure 10: Mangrove wetlands in Eluru (West Godavari) District

2.1.9. Mangrove wetlands in Anakapalli District

Mangrove cover in Anakapalli District covers an area of approximately 1.2 km^2 (Fig. 11). The mangrove wetlands are located in the low-lying estuarine regions of the Sarada River and along the tidal creeks draining into the Bay of Bengal. *Avicennia marina* is the dominant mangrove species.

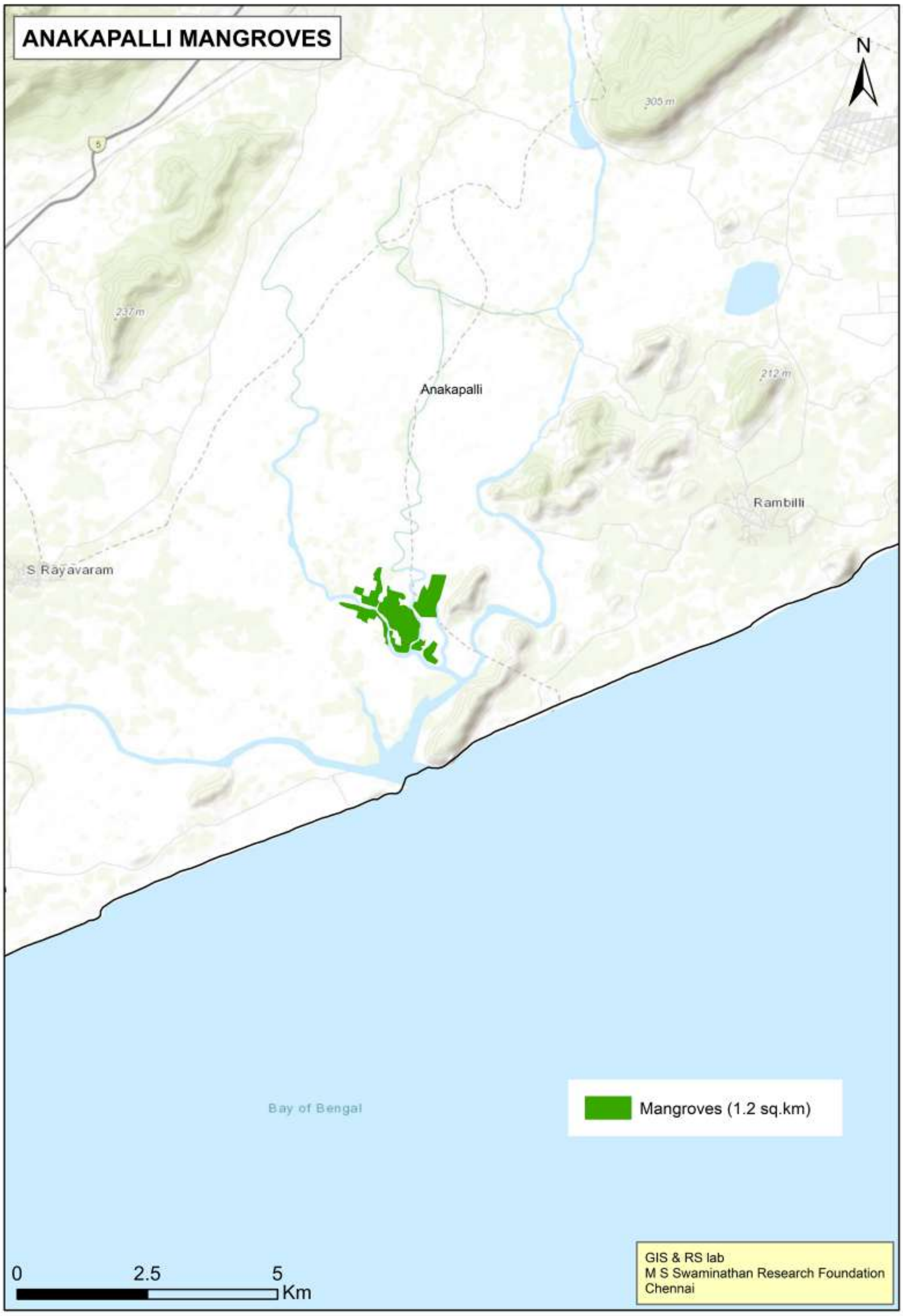


Figure 11: Mangrove wetlands in Anakapalli District

2.1.10. Mangrove wetlands in Visakhapatnam District

The Visakhapatnam mangroves, covering an area of 0.51 km^2 (Fig. 12), are located near the industrial zones along the city's harbour and estuarine backwaters. Despite their limited extent, they play a crucial role in shoreline stabilization and local biodiversity support.

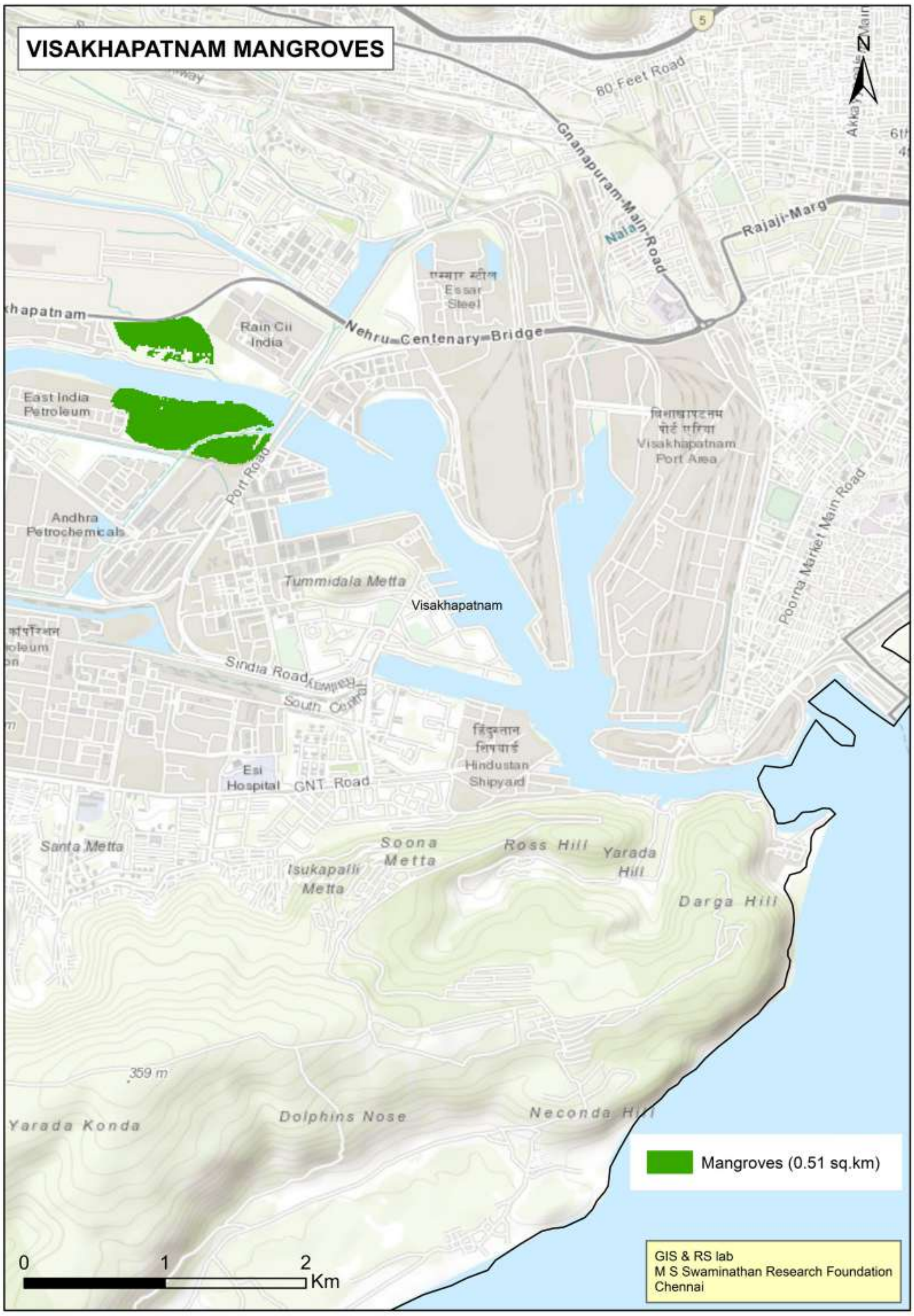


Figure 12: Mangrove wetlands in Visakhapatnam District

2.1.11. Mangrove Extent as per Indian State Forest Report, 2023

The mangrove cover in Andhra Pradesh is 421.43 km^2 (FSI, 2024). Compared to the 2021 assessment, the extent of mangroves increased by 13.01 km^2 in 2023 (Table 7). Mangroves in the Krishna, Kakinada, Bapatla, and B.R. Ambedkar Konaseema districts contribute 90% of the mangrove cover in Andhra Pradesh.

Table 7: District-wise mangrove wetlands in Andhra Pradesh (FSI, 2024)

S.No.	District	Total area (km^2)	Percentage
1	Bapatla	72.92	17.32
2	Eluru	0.02	0.00
3	Kakinada	113.79	27.03
4	Dr. B. R. Ambedkar Konaseema	74.42	17.68
5	Krishna	148.45	35.26
6	Prakasam	0.75	0.18
7	Sri Potti Sriramulu Nellore	8.66	2.06
8	Srikakulam	0.82	0.19
9	Tirupati	1.29	0.31
10	Visakhapatnam	0.31	0.07
	Total	**421.43**	**100**

2.2. Floral Diversity in Andhra Pradesh

The mangroves of Andhra Pradesh, particularly the Godavari and Krishna wetlands, host 40 species, including true and associated mangrove species. *Avicennia marina* and *Excoecaria agallocha* are the dominant species in Andhra Pradesh. *Aegiceras corniculatum, Lumnitzera racemosa, Sonneratia apetala, Avicennia alba, Rhizophora apiculata, Bruguiera gymnorrhiza, B. cylindrica* and *Ceriops decandra* are also common in the wetlands of Andhra Pradesh. *Aegialitis rotundifolia, Brownlowia tersa, Ceriops tagal, Kandelia candel, Rhizophora annamalayana, Sonneratia alba, Scyphiphora hydrophyllacea, Xylocarpus granatum*, and *X. moluccensis* are some of the rare species found in the Godavari and Krishna mangrove wetlands. Among these *Aegialitis rotundifolia* and *Brownlowia tersa* are near threatned species (Ragavan et al, 2016). Detailed species diversity is given in Chapters 3 and 4.

2.3. Rivers of Andhra Pradesh

Andhra Pradesh is richly endowed with a network of rivers that contributes significantly to the state's agriculture, economy and ecology. The major rivers flowing through the state include the Godavari, Krishna, Pennar, and Vamsadhara (Fig. 13). These rivers support large irrigation projects and dams, such as Nagarjuna Sagar, Srisailam, Cotton Barrage, and Prakasam Barrage, making the state one of the key agricultural zones in India.

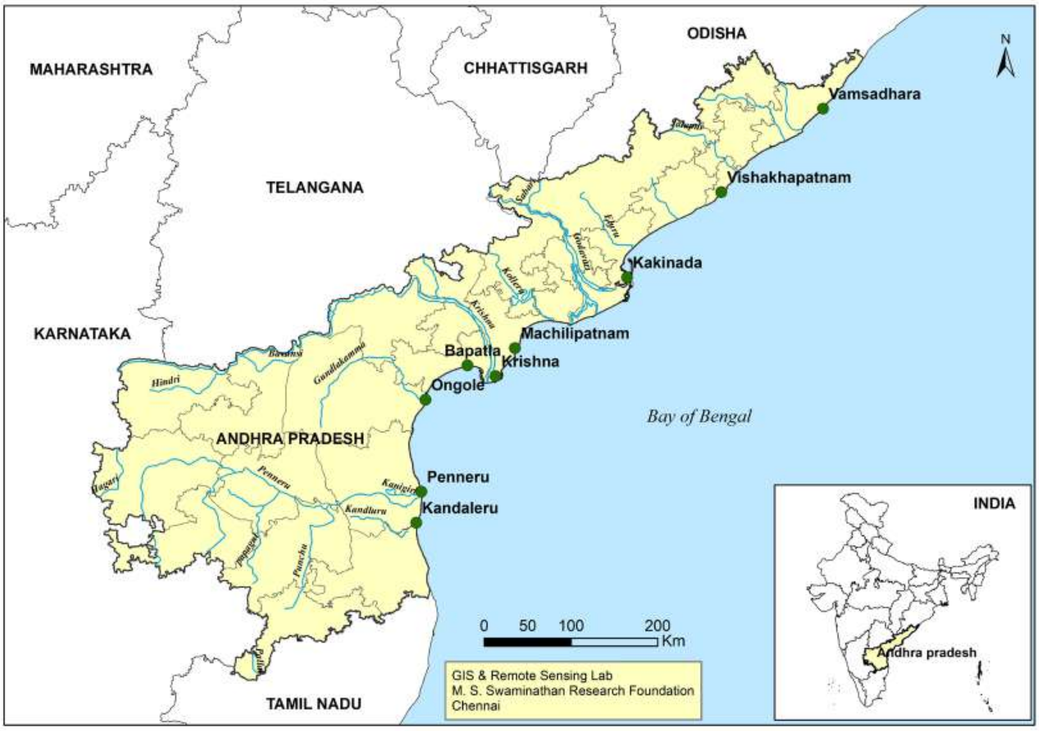


Figure 13: Major rivers in Andhra Pradesh

2.3.1. The Godavari River Basin

The Godavari River basin extends between 73°24' and 83°4' E and 16°19' and 22°34' N. The Godavari is the second-largest river in India, covering approximately 9.5% of the country's total geographical area and serving as an interstate boundary between Telangana and Maharashtra, as well as between Telangana and Chhattisgarh, and between Telangana and Andhra Pradesh. It is the largest in peninsular India in terms of length, catchment area, and discharge; hence, it is referred to as the Dakshina Ganga (The Ganges of the South). The region features tablelands with elevations ranging from 600 to 1200 meters. Originating near Triambakeshwar in Nashik district in the Sahyadri hill ranges, the river flows through Ahmednagar, Aurangabad, and Nanded districts before entering Telangana and finally joining the Bay of Bengal near Yanam (Union Territory of Puducherry) in Andhra Pradesh. It flows through the Eastern Ghats and emerges into the plains at Polavaram. The Godavari River splits into the Gautami and Vasishta branches at Dhavaleswaram near Rajamahendravaram (Rajahmundry).

The Godavari River basin spans an area of 3,02,065.10 km^2 with a maximum length and width of approximately 995 km and 583 km, respectively. It has catchments in seven states: Maharashtra, Telangana, Chhattisgarh, Madhya Pradesh, Andhra Pradesh, Karnataka, and Odisha. Major tributaries on the right bank include the Pravara and Manjira. At the same time the Purna, Pranahita, Indravati, and Sabari join from the left (Fig. 14). Annual rainfall in the basin ranges from 881 to 1395 mm, with an average of 1110 mm. The central part of the basin receives less rainfall, whereas the Indravati, Pranahita, and Sabari areas receive more. Significant water inflows to the Godavari River come from the Indravati, Pravara, Wardha, Wainganga, Kanhan, Pench, and Penuganga rivers. About 968 structures, including dams, barrages, weirs and anicuts, were constructed to store water for irrigation and other purposes, the highest in India. The Coringa Wildlife Sanctuary, located in the Kakinada district is part of the Godavari mangrove wetland.

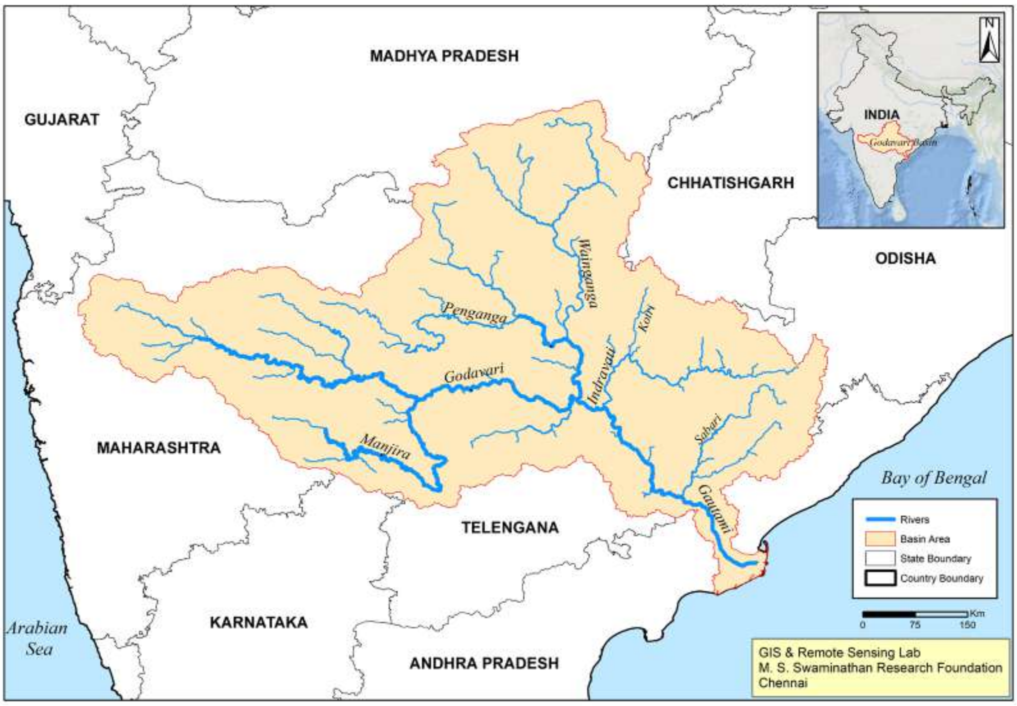


Figure 14: The Godavari River Basin

2.3.2. The Krishna River Basin

The Krishna River is the third-longest in India, after the Ganga and the Godavari, and the second-longest river in Andhra Pradesh. It ranks fourth in water inflows and river basin area, after the Ganges, Indus, and Godavari. The Krishna River basin encompasses parts of Karnataka (113,271 km^2), Telangana and Andhra Pradesh (76,252 km^2), and Maharashtra (69,425 km^2), covering an area of 258,948 km^2 or nearly 8% of India's total geographical area. Originating in the Western Ghats at an elevation of 1,337 meters just north of Mahabaleshwar, the Krishna River flows approximately 1,400 km to the Bay of Bengal. The basin's maximum length and width are about 701 km and 672 km, respectively, lying between 73°17' and 81°9' E and 13°10' and 19°22' N.

Major tributaries of the Krishna River include the Ghataprabha, Malaprabha, Bhima, Tungabhadra, and Musi (Fig. 15). Various important soil types, including black soil, red soil, laterite soil, and saline alkaline soils, characterise the basin. The average annual rainfall in the Krishna basin is 784 mm, with 90% of the rainfall occurring during the monsoon season, primarily from July to September. The Krishna River basin has 660 Dams, 12 barrages, 58 weirs, six anicuts and 119 lift irrigation projects. The River Krishna splits into the Hamsaladivi canal near Avanigadda, and it is further divided into the Gollamatta, Nadimeru, and main the Krishna River near Edurumondi village.

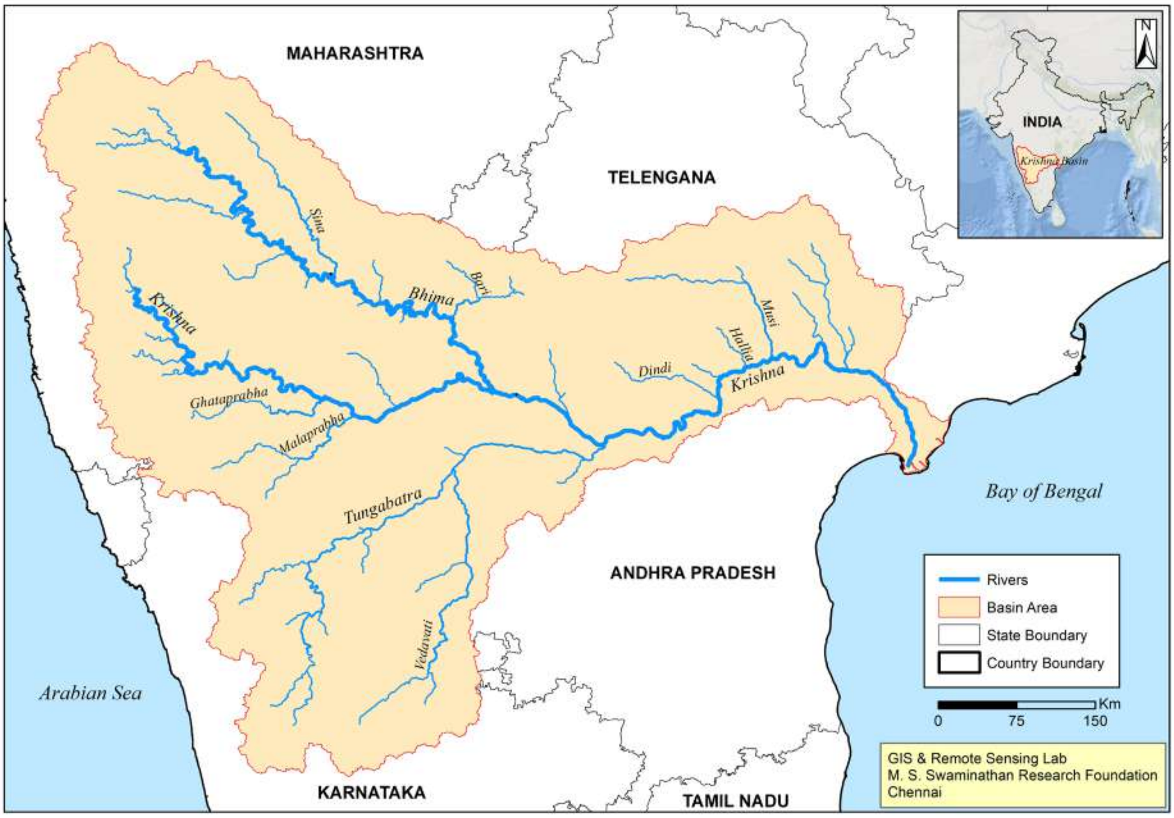


Figure 15: The Krishna River Basin

2.3.3. The Pennar River Basin

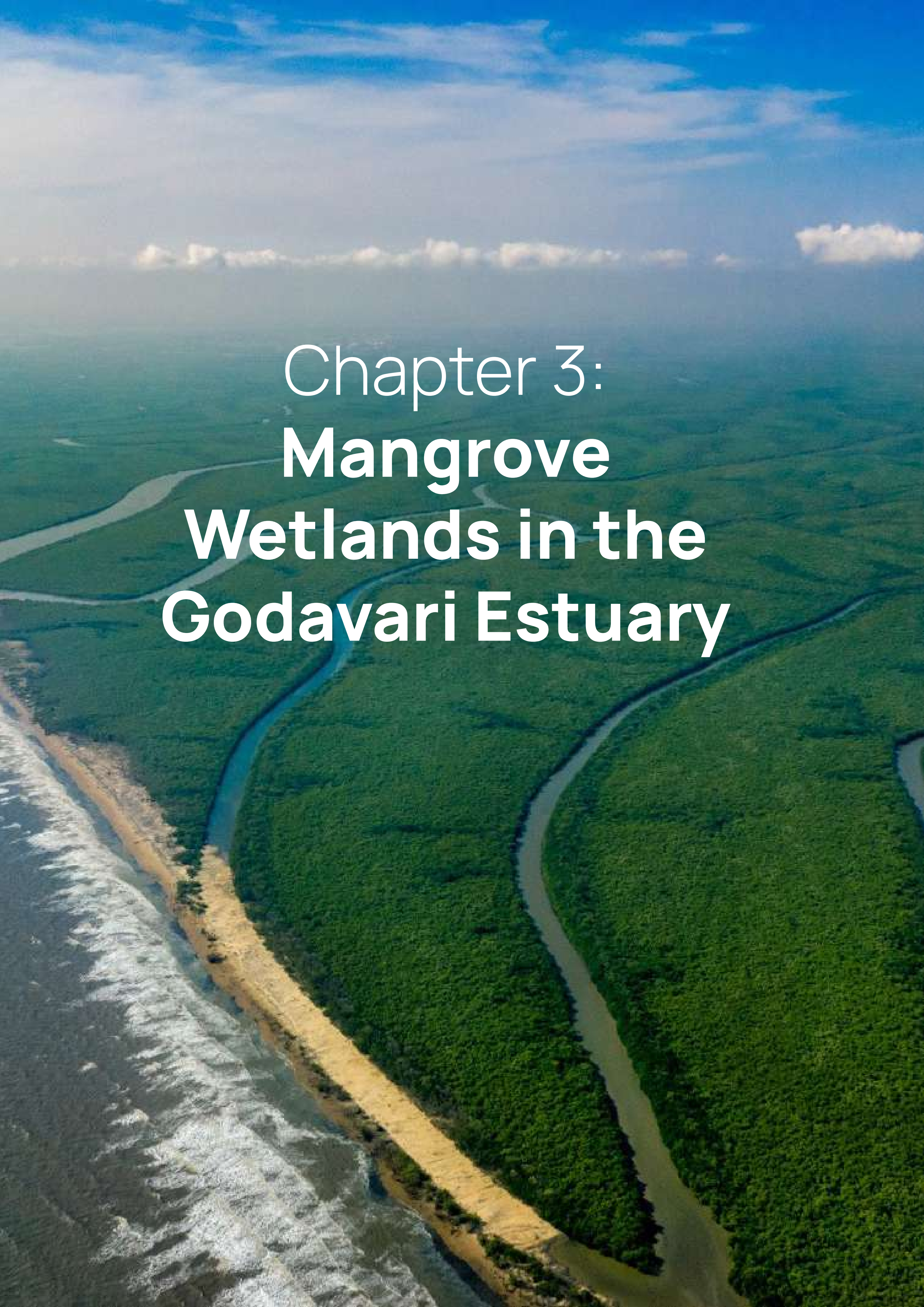
The Pennar, also known as Uttara Pinakini, is one of the major rivers in Andhra Pradesh. It originates from the Chenna Kesava hill in Chikkaballapura district, Karnataka, and flows eastward towards the Bay of Bengal, covering a distance of 597 km. The river basin spans 55,213 km^2 across Andhra Pradesh and Karnataka, lying between 77°1' - 80°10' E and 13°18' - 15°49' N. Major left-bank tributaries include the Jayamangali, Kunderu, and Sagileru and the right-bank tributaries are the Chiravati, Papagni, and Cheyyeru.

2.3.4. The Vamsadhara River Basin

The Vamsadhara is an east-flowing river between the Godavari and Mahanadi rivers, flowing through north-eastern Andhra Pradesh and southern Odisha. The river flows 254 km before joining the Bay of Bengal at Kalingapatnam, Andhra Pradesh. The catchment area of the river is 10,830 km^2. Bansadhara in Odisha originates near Kalyansinghpur in the Rayagada district of Odisha, and the Mahendratanaya River, which originates in the Gajapati district of Odisha, is a major tributary of the Vamsadhara.

2.4. Climatic conditions of Andhra Pradesh

The climate of Andhra Pradesh is typically hot and humid, with significant variations across different geographical areas. The summer season extends from March to June, with the coastal plains experiencing higher temperatures than other parts of the state, ranging from 30°C to 41°C. The humidity is higher in the coastal areas due to their proximity to the Bay of Bengal. The southwest monsoon (June-September) contributes 68.5% of the rainfall, while the northeast monsoon (October-December) accounts for 22.3%. The remaining 9.2% occurs during the winter and summer seasons. Annual rainfall ranges from 1045 mm to 1170 mm, with an average of 1100 mm (Ravishankar et al., 2004). The northern coastal districts of Andhra Pradesh receive the highest mean rainfall during the Southwest monsoon, while districts in the south receive less rainfall. The Anantapur district receives the lowest mean annual rainfall. The winter season typically spans from December to February, which is generally mild due to the state's extensive coastline.



Chapter 3:
Mangrove Wetlands in the Godavari Estuary

Chapter 3: Mangrove Wetlands in the Godavari Estuary

The Godavari estuary is the largest in peninsular India, with extensive mangroves distributed along the coastal areas of the Kakinada and B.R. Ambedkar Konaseema districts. The main Godavari River is divided into two branches: the northward-flowing Gautami Godavari and the southward-flowing Vasishta Godavari. The Godavari mangrove wetlands constitute the largest mangrove area in Andhra Pradesh. It is located between 16° 30' - 17° N and 82° 14' - 82° 23' E, spread over the coastal areas of Kakinada and Dr. B.R. Ambedkar districts of Andhra Pradesh. The extent of this wetland is about 316 km^2 (Rajesh Mittal, 1993), of which 235.70 km^2 is in the Coringa Wildlife Sanctuary. The mangrove wetland has been protected for over 100 years under the Madras Forest Act of 1882. The mangroves were systematically felled on a 25-year rotation period from 1930 to 1970. Fishing and grazing within the mangroves have been traditionally practised, even after the Sanctuary was declared in 1978.

In the Godavari mangrove wetland, Kakinada Bay is one of the important fishing grounds situated in the northeast side of the Sanctuary. The bay on the southern side is shallow, with a mean depth of about 2 m, and it is deeper on the north-eastern side (6-8 m). Corangi and Gaderu are the distributaries branching off from the northern side of the River Godavari, supplying freshwater into the Coringa mangroves. Apart from these two major distributaries, the Tulyabhaga drain and several small creeks and canals are interconnected, forming a network of canals that supply tidal water to the mangroves. Freshwater flows into the mangrove wetland for nearly six months in a year, and the peak flow occurs from July to September, coinciding with the southwest monsoon. The climate is sub-humid, with a mean annual rainfall ranging from 1,200 to 1,300mm. The area receives approximately 70% of its rainfall during the southwest monsoon and the remainder during the northeast monsoon and the summer months. The dry season lasts approximately six months, from December to May. The annual mean temperature is 28°C. The mean sea level in the Godavari mangrove wetland is approximately 0.87 m. The maximum high tide is 1.54 m, and the minimum high tide is 0.20 m (Ramasubramanian et al., 2006).

3.1. Geo-Morphology

The geo-morphology of the Godavari estuary is shaped by the interaction of fluvial, tidal, and marine processes, resulting in a highly dynamic and ecologically sensitive landscape. The Godavari Delta is a classic example of an arcuate delta, formed by the divergence of distributary channels such as the Gautami and Vasishta (Fig. 16). The river transports sediments, especially during the monsoon season, contributing to the development of mudflats, sandbars, and lagoons and thus playing a critical role in shaping the estuarine morphology. The estuarine system comprises an active deltaic plain, an older floodplain, and a range of coastal features shaped by tidal currents and wave action. The active delta is relatively flat, with low relief, and is subject to seasonal flooding. Over the years, the delta has prograded due to continuous sediment deposition. River water discharge during monsoon, tidal flows, and wave action control the sediment dynamics in the Godavari estuary. This region experiences semi-diurnal tides, which enhance sediment redistribution and foster alternating phases of erosion and accretion. The rate of shoreline erosion along the northern side of the river up to Uppada village is high.

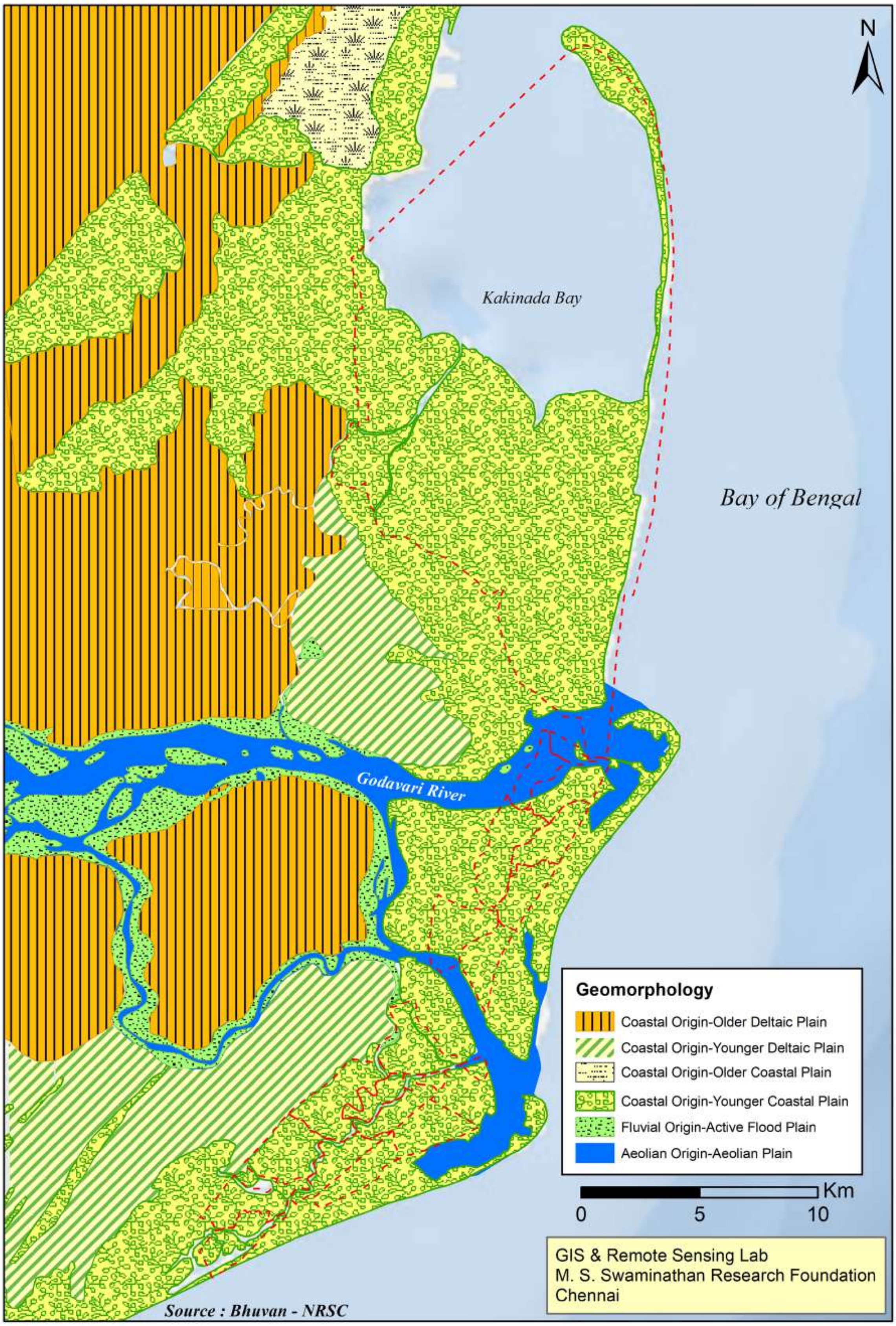


Figure 16: Geo-Morphology of the Godavari delta

3.2. Reserve Forests

3.2.1. The Coringa Wildlife Sanctuary

The Coringa Wildlife Sanctuary is located in the Kakinada District of Andhra Pradesh, about 6 km south of Kakinada. It is situated between 16°30' - 17°00' N latitudes and 82°14' - 82°23' E longitudes. The Sanctuary was declared under Section 18 of the Wildlife Protection Act, 1972 (Central Act No. 53 of 1972) in 1978 through G.O. Ms No. 484, Forests and Rural Development (For.III) Department. The Sanctuary has three reserve forests, namely the Coringa Reserve Forest, Coringa Extension Reserve Forest, and Bhyravapalem Reserve Forest, which are notified under Section 16 of the Madras Forest Act, 1882, and Section 15 of the AP Forest Act, 1967. The extent of Coringa Wildlife Sanctuary is 235.70 km², in which almost half of the region (50.28%) is covered by water bodies, leaving approximately 117.17 km² (49.71%) with mangrove forests. The Coringa River, originating to the west of Yanam town, flows north and enters the Kakinada Bay. The Gaderu River, which originates near Bhyravapalem, approximately 10 km East of Yanam town, flows northwards before joining the Kakinada Bay.

- Coringa Reserve Forest: Notified as a Reserve Forest in G.O.Ms. No.202, Revenue Dept. Dated: 12th May 1888 to take effect from 15th June 1888.
- Coringa Extension Reserve Forest: Notified as Reserve Forest vide Fort Saint George Gazette No.36, Dated 5th February 1921.
- Bhyravapalem Reserve Forest: Notified as Reserve Forest in G.O. Ms. No.103-Forest and Rural Development (For.III), Dated 24th April 1974.

The confluence of the Gautami Godavari River in the Bay of Bengal is located on the southern side of the Sanctuary. The mangroves of Coringa Wildlife Sanctuary receive freshwater from the distributaries of the Gautami-Godavari River and neritic waters from Kakinada Bay, including the Coringa and Gaderu rivers.

3.2.2. Other Reserve Forests in the Godavari Wetland

The reserve forests south of the Coringa Wildlife Sanctuary are Rathikaluva, Masanitippa, Matlatippa, Balusitippa, Kottapalem, and Kandikuppa, which are part of the B.R. Ambedkar Konaseema District (Fig. 17). The extent of the reserve forest in the Godavari wetland is given in Table 8.

Table 8: Reserve Forest Areas in the Godavari Wetland

S. No.	Reserve Forest	Extent in Coringa Wildlife Sanctuary in Kakinada District (km^2)	Extend in B R Ambedkar Konaseema Dist (Non-Sanctuary area) (km^2)
1	Coringa	31.57	
2	Coringa Extension	194.42	
3	Bhairavapalem	9.72	
4	Rathikaluva	-	20.43
5	Masantippa	-	13.00
6	Matlatippa	-	4.45
7	Balusitippa	-	5.46
8	Kottapalem	-	0.66
9	Kandikuppa	-	39.84
	Total	**235.71**	**83.84**

Figure 17: The Reserve Forests in the Godavari wetland

3.3. Flora of the Godavari wetland

The mangrove forest in the Coringa Wildlife Sanctuary is dense and healthy due to the prolonged freshwater discharge from the Thulyabhaga drain, the Corangi River, and the Gaderu River. The Godavari River drains large amounts of freshwater with nutrient-rich sediments. The Corangi and Gaderu distributaries bring freshwater from the River Godavari, while the Thulyabhaga drain discharges water from the agricultural fields. The freshwater is available for more than six months, keeping the salinity below 30 parts per thousand (ppt), which is ideal for the mangroves to grow luxuriantly. The freshwater-dependent species and mangrove associates are more on the landward side of the Sanctuary. In contrast, true mangroves are more along the seaward side (between Gaderu and the Bay of Bengal), where the salinity is high, given its proximity to the sea. *Avicennia marina* and *Excoecaria agallocha* are dominant species, followed by *Aegiceras corniculatum, Lumnitzera racemosa* and *Volkameria inermis* on the landward side. Some of the trees of *Avicennia officinalis* have a girth of more than 2.5 m and are 10 m tall near the Thulyabhaga drain and along the Corangi River. Similarly, *Avicennia marina* trees with a 2.0 m girth and 10 m height are also found near the Kakinada Bay, adjoining the Thulyabhaga drain. *Acanthus ilicifolius, Myriostachya wightiana, Hibiscus tiliaceus*, and *Thespesia populneoides* are found along the Corangi and Thulyabhaga drain, while *Rhizophora* spp., *Bruguiera gymnorrhiza, Bruguiera cylindrica, Ceriops decandra* and *Xylocarpus moluccensis* are more in the seaward side. The mangroves along the Kakinada Bay are dense. *Sonneratia apetala* and *Avicennia alba* are abundant in this zone, as the area receives daily tidal water inundation. *Porteresia coarctata*, a grass, is abundant in the Kakinada Bay region. It is a submergence-tolerant species, reaching a height of approximately 1.5 m. The halophytes, namely *Salicornia brachiata, Sesuvium portulacastrum, Suaeda maritima*, and *Suaeda nudiflora*, are found in the degraded and high-saline areas where tidal water flow is occasional. *Sarcolobus carinatus*, a climber primarily associated with *Excoecaria agallocha*, is found. The grass species *Myriostachya wightiana, Porteresia coarctata, Fimbristylis ferruginea*, and *Aeluropus lagopoides* are also found in the wetland.

The southern side of the delta, which falls under the reserve forests (non-sanctuary), shows higher species diversity than the Coringa Wildlife Sanctuary. The dominant species is *Avicennia marina*, followed by *Excoecaria agallocha, Lumnitzera racemosa* and *Aegiceras corniculatum*. Apart from these, *Xylocarpus moluccensis, Bruguiera gymnorrhiza* and *Bruguiera cylindrica* are observed. *Scyphiphora hydrophyllacea*, a rare mangrove species, is found near the Sacramento Lighthouse in a small pocket. The M S Swaminathan Research Foundation (MSSRF) and The Andhra Pradesh State Forest Department (APFD) successfully propagated and transplanted the species through air layering at the Mangrove Genetic Resources Conservation Centre in the Chollangi mangrove nursery (Ramasubramanian et al., 2020). Many Rhizophoraceae family members are recorded in the southern part of the delta, indicating the prevalence of more saline water in this zone.

Avicennia marina

Bruguiera gymnorhiza

Ceriops decandra

Ceriops tagal

Rhizophora apiculata

Rhizophora mucronata

Lumnitzera racemosa

Scyphiphora hydrophylacea

Brownlowia tersa

Xylocarpus moluccensis

Sonneratia apetala

Sonneratia alba

Mangrove species diversity

Apart from the above tree species, the grass species, namely *Myriostachya wightiana, Porteresia coarctata, Fimbristylis ferruginea*, and *Aeluropus lagopoides*, as well as climbers such as *Ipomoea pes-caprae* and *Sarcolobus carinatus*, are also observed. The halophytes, namely *Salicornia brachiata, Sesuvium portulacastrum, Suaeda maritima*, and *Suaeda nudiflora*, are recorded in the degraded areas and in the high saline areas along with *Neltuma juliflora*, where tidal water flow is very occasional. Mangrove-associated species *Tamarix troupii* and *Hibiscus tiliaceus* are found in the Rathikalava area. The Andhra Pradesh Forest Department raised *Casuarina* plantations along the coast. *Neltuma* is colonising in the elevated areas, and the extent is more in the southern part of the delta than in the Coringa Wildlife Sanctuary. Though the species diversity is high, the health of the mangroves is not as good as that of the Coringa Wildlife Sanctuary. The reasons may be the availability of fresh water in the Coringa Wildlife Sanctuary for more than six months. The runoff also brings a lot of nutrients, whereas the mangroves in the southern part of the delta receive mostly tidal water (seawater), which is low in nutrients. The soil in the Coringa Wildlife Sanctuary is predominantly clayey, while the southern part of the delta is a mix of clay and sand.

The mangrove floral diversity revealed a total number of 40 mangrove and mangrove-associated species (Table 9). There are 18 true mangrove species, and most of them flower in June and fruit in October and November. Apart from the true mangroves, 11 mangrove associate species, four grass species and seven halophytes are found in the Godavari wetland. *Brownlowia tersa, Rhizophora annamalayana, Sonneratia alba, Scyphiphora hydrophyllacea*, and *Xylocarpus moluccensis* are the rare species found in the Godavari mangrove wetland. In the Godavari mangrove wetland, the aboveground and belowground carbon were 41.31 ±13 Mg/ha and 71.38±20 Mg/ ha, respectively, and the total carbon was 112.69±-26 Mg/ha (Katiyar et al., 2020).

Table 9: Mangroves and Mangrove associated species in the Godavari Wetland

S. No.	Species name and Family	Telugu name	Status
1	*Avicennia alba* Bl. Acanthaceae	Vilava mada	Common
2	*Avicennia marina* (Forsk.) Vierh Acanthaceae	Tella mada	Common
3	*Avicennia officinalis* L. Acanthaceae	Nalla mada	Common
4	*Acanthus ilicifolius* L. Acanthaceae	Alchi	Common near the creeks
5	*Aegiceras corniculatum* (L.) Blanco Myrsinaceae	Guggilam	Common
6	*Brownlowia tersa* (L.) Kosterm Malvaceae	-	Rare
7	*Bruguiera cylindrica* (L.) B. Rhizophoraceae	Urudu	Common
8	*Bruguiera gymnorrhiza* (L.) Savigny Rhizophora-ceae	Kandriga	Common

S. No.	Species name and Family	Telugu name	Status
9	*Ceriops decandra* (Griff.) Ding Hou Rhizophora-ceae	Togara	Rare
10	*Excoecaria agallocha* L. Euphorbiaceae	Tilla	Common
11	*Lumnitzera racemosa* Wild. Combretaceae	Thanguda	Common on the land-ward side
12	*Rhizophora annamalayana* Kathir. Rhizophorace-ae	-	Rare
13	*Rhizophora apiculata* Bl. Rhizophoraceae	Ponna	Common
14	*Rhizophora mucronata* Lamk. Rhizophoraceae	Ponna	Common
15	*Scyphiphora hydrophyllacea* Rubiaceae	Nara than-duga	Rare
16	*Sonneratia alba* J E Smith Lythraceae	Kalinga	Common near the river mouth
17	*Sonneratia apetala* Buch.-Ham. Lythraceae	Kalinga	Common near the river mouth
18	*Xylocarpus moluccensis* (Lamk.) M. Roem. Melia-ceae	Senuga	Rare
Trees – Mangrove Associates			
1	*Volkarmeria inermis* Gaertn. Verbanaceae	Pisingi	Common along the creeks on the landward side
2	*Hibiscus tiliaceus* L. Malvaceae	Attakanara	Rare
3	*Pongamia pinnata* L. Fabaceae	Ganuka	Rare along the Corangi Creek
4	*Tamarix troupii* Hole. Tamariaceae	Palivelu	Trees are less frequent along the river Goda-vari
5	*Thespesia populneoides* (Roxb.) Kostel Malvaceae	Ganguravi	Rare
Climbers –Mangrove Associates			
1	*Caesalpinia crista* L. Caesalpiniaceae	Rachis	Common
2	*Dalbergia spinosa* Roxb. Fabaceae	Chillinga	Common
3	*Derris trifoliata* Lour. Fabaceae	Nalla theega	Common
4	*Ipomoea pes-caprae* (L.) Sweet Convolvulaceae	-	Common along the beachside
5	*Ipomoea tuba* (Schltdl.) G. Don Convolvulaceae	Tella teega	Common
6	*Sarcolobus carinatus* Wall. Asclepiadaceae	Balaboddu teega	Common
Grass			
1	*Aeluropus lagopoides* (L.) Trin Poaceae	-	Common in degraded mangrove areas

S. No.	Species name and Family	Telugu name	Status
2	*Fimbristylis ferruginea* (L.) Vah. Cyperaceae	-	Common near the river mouth
3	*Myriostachya wightiana* (Necs ex. Steud.) Hook.f. Poaceae	Dhaba gaddi	Common along the creeks on the landward side
4	*Porteresia coarctata* (Roxb.) Tateoka Poaceae	Yellugaddi	Kakinada Bay
Halophytes			
1	*Cressa cretica* L Convolvulaceae	-	Common in degraded and elevated areas
2	*Heliotropium curassavicum* L. Boraginaceae	-	Common in degraded and elevated areas
3	*Salicornia brachiata* Roxb. Amaranthaceae	-	Common near degrad-ed and elevated areas
4	*Sesuvium portulacastrum* (Linn.) Linn. Aizoaceae	-	Common in degraded and elevated areas
5	*Suaeda maritima* (L.) Dumort. Amaranthaceae	Elakura	Common in degraded and elevated areas
6	*Suaeda nudiflora* (Willd.) Moq. Amaranthaceae	Elakura	Common in degraded and elevated areas
7	*Tecticornia indica* (Willd.) K.A.Sheph. & Paul G.Wilson, (Syn *Arthrocnemum indicum)* Amaran-thaceae	-	Common in degraded areas near the Sacra-mento lighthouse

3.4. Mangrove Species Zonation

Dense stands of *Avicennia alba* and *Sonneratia apetala* are seen near the mouths of the Corangi River and Thulyabhaga drain in the Kakinada Bay. In the newly formed mudflats in the Kakinada Bay, extensive patches of *Porteresia coarctata* and seagrass *Halophila ovalis* are found. The entire mudflat area in the Kakinada Bay is submerged during high tides. *Porteresia coarctata* plays a crucial role as a pioneer species in ecological succession. Its ability to trap and stabilise sediments facilitates the gradual establishment of other plant species, such as *Avicennia alba* and *Sonneratia apetala.* The eastern side of the Gaderu River has more Rhizophoraceae members, such as *Bruguiera cylindrica, B. gymnorrhiza, Rhizophora apiculata* and *R. mucronata*, than the western side of the Gaderu River. However, on both sides, *Avicennia marina* is the dominant species. Along the seaward side, *Rhizophora* spp. are found along the creeks and in the landward side, *Avicennia marina* is found. Degraded patches consist of halophyte species such as *Suaeda* and *Salicornia* found on the landward side. In the areas where the tidal inundation is less, patches of *Excoecaria agallocha, Aegiceras corniculatum, Ceriops decandra*, and *Lumnitzera racemosa* are found.

Species-level zonation of mangroves was mapped using IRS LISS IV satellite imagery (5 m resolution). A supervised classification technique was applied based on spectral differences among species. In the Godavari mangrove wetland, five major mangrove species zones, namely *Avicennia marina, A. officinalis, Excoecaria agallocha, Rhizophora* spp., and *Aegiceras corniculatum*, are classified (Fig. 18). However, other species are also mixed in these zones to a lesser extent.

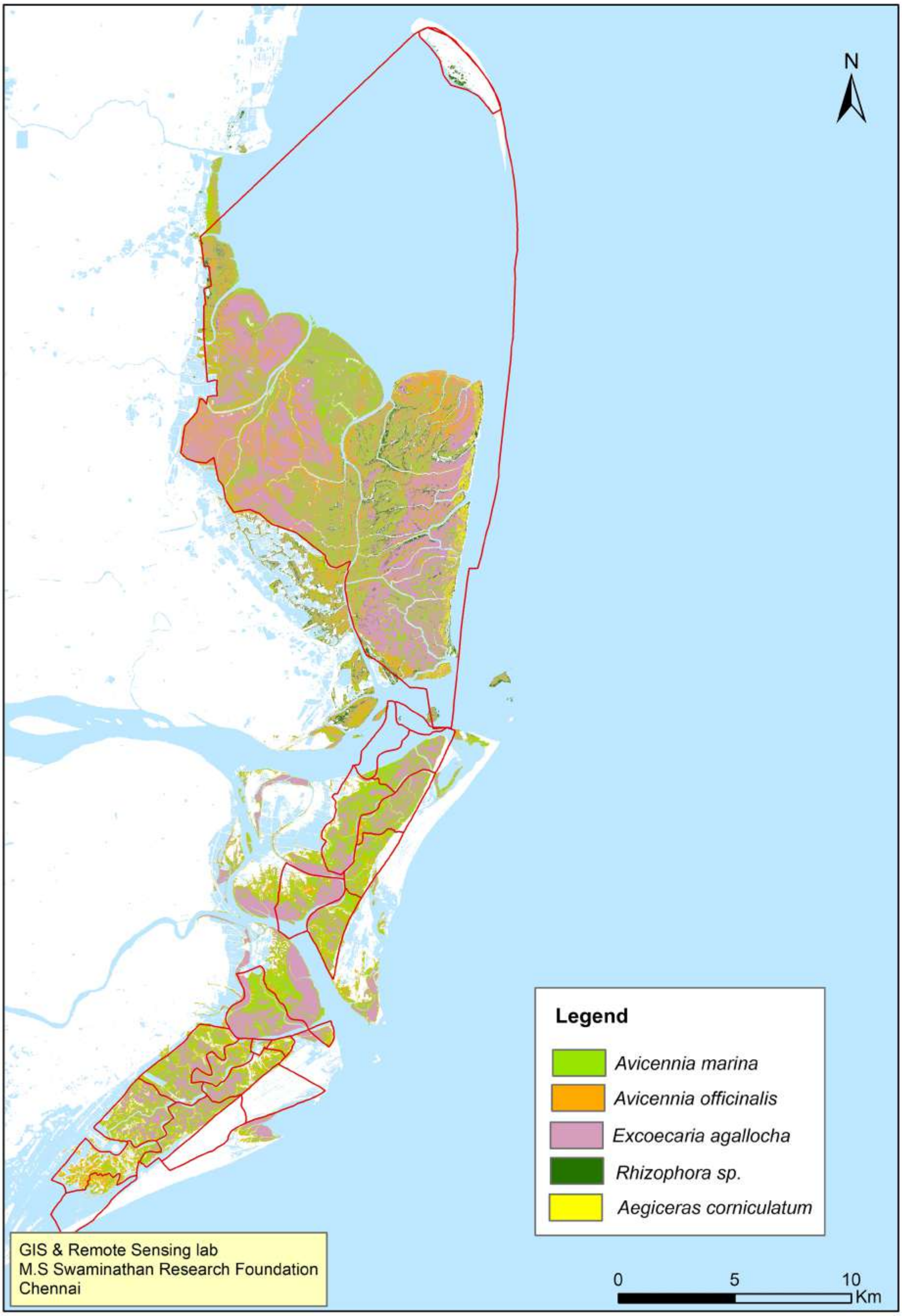


Figure 18: Species-wise distribution in the Godavari mangrove forest

3.5. Density mapping of the Godavari Mangroves (2023)

Mangrove density cover in the Krishna and Godavari regions was analysed using the Normalised Difference Vegetation Index (NDVI) derived from LISS IV IRS satellite imagery. Based on NDVI values, mangrove density was classified into three categories (Alex et al., 2017):

- NDVI 0.2 to 0.4: Open mangroves
- NDVI 0.4 to 0.6: Moderately dense mangroves
- NDVI > 0.6: Dense mangroves

The extent of dense mangroves (with 60% canopy cover) is 12,693 hectares, reflecting a mature and healthy ecosystem. Freshwater availability for a substantial period, combined with nutrient-laden sediments, favours the health of the mangroves. The sheltered coast with less wave action in Kakinada Bay facilitates the accretion of sediments in the bay, favouring the dense growth of *Avicennia alba* and *Sonneratia apetala*. Moderately dense mangroves, primarily in the restored area, cover an area of 5,508 hectares, indicating moderate health and a gradual transition to thick vegetation. Open mangroves, covering 2,035 hectares, are sparse and scattered throughout the area (Fig. 19). Dense mangrove areas are mainly concentrated around river mouths and intertidal regions due to favourable factors such as tidal water flow and sediment deposition. In contrast, open mangroves are typically found in elevated areas where tidal action is minimal and anthropogenic pressures are relatively high.

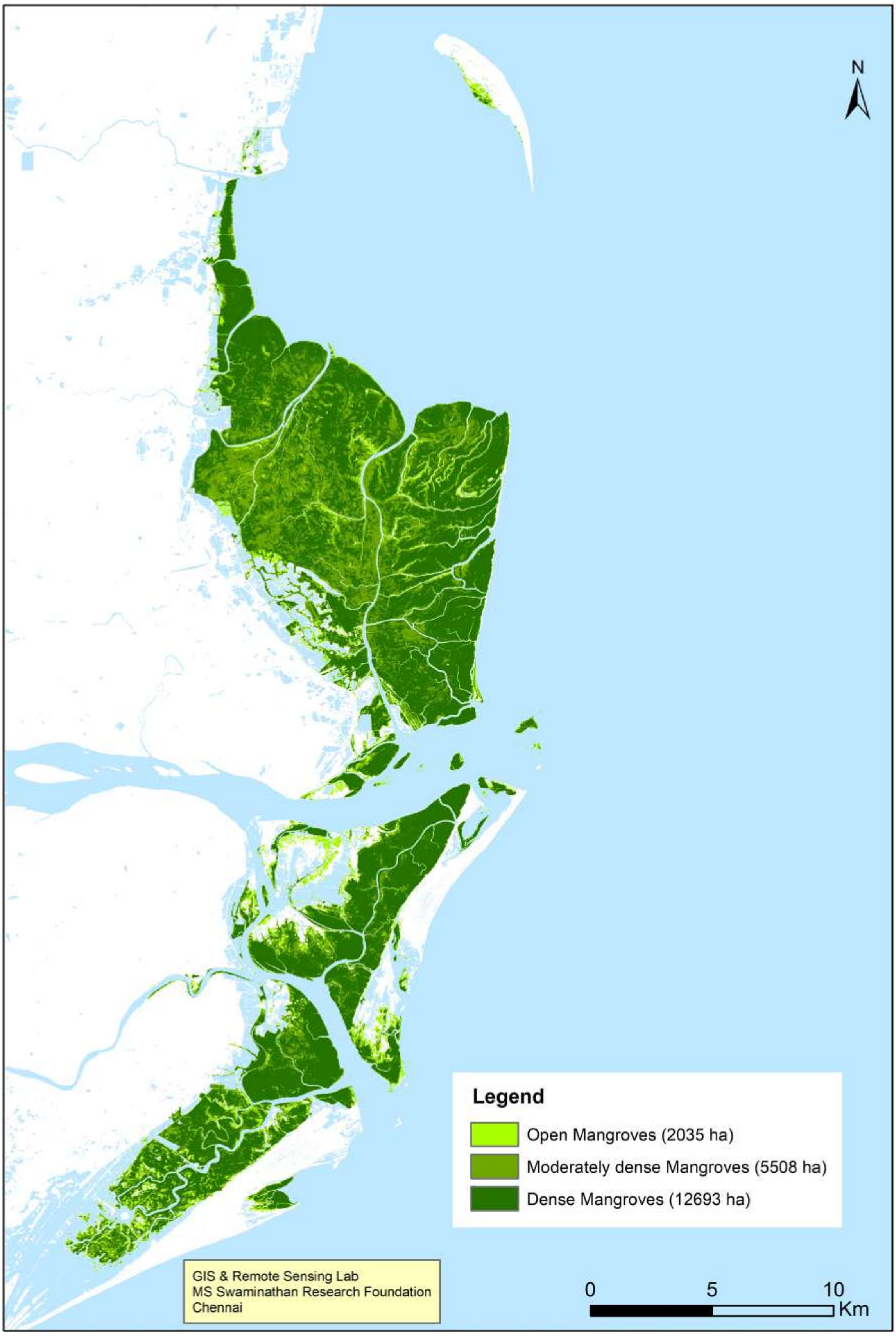


Figure 19: Mangrove Canopy Density in the Godavari mangrove forest (2023)

3.6. Fauna in the Mangrove Wetlands

The mangrove ecosystem contributes rich aquatic faunal diversity. Ray et al. (2022) reported 231 species of finfish in the Godavari estuary. Among these, *Silonia childreni* is an endangered species, while *Tenualosa toli, Cirrhinus cirrhosis,* and *Wallago attu* are vulnerable (Sivakumar et al., 2017). In an earlier study, 153 species of ichthyofauna were recorded, of which three species - *Epinephelus malabaricus, Wallago attu,* and *Platycephalus indicus* - are categorised as threatened species. *Piarachtus brachypomus* is recorded in aquaculture ponds and along the creeks in the Coringa Wildlife Sanctuary. *Leiognathus equluus, Mystus gulio, Oreochromis mossambicus, Tetraodon fluviatilis* and *Dendrophysa russelli* are the abundant species in the estuary. Fourteen species of mammals belonging to 10 families are reported, including *Prionailurus viverrinus* (fishing cats), *Delphinus delphis, Susa chinensis, Stenella longirostris*, and *Tursiops truncates*, which are listed in Schedule-I of the Indian Wildlife Protection Act 1972. In contrast, *Macaca mulatta, Macaca radiata, Felis chaus, Paradoxurus hermaphrodites, Herpestes edwardsii, Canis aureus*, and *Lutrogale perspicillata* (Smooth Coated Otters) are listed in Schedule II (Mukherjee et al., 2016; Sivakumar et al., 2017; Gridhar Malla et al., 2023). The smooth-coated otter is classified as Vulnerable (VU) by the International Union for the Conservation of Nature (IUCN) (de Silva et al., 2023) and is included in Appendix II of the Convention on International Trade in Endangered Species (CITES). *Lutrogale perspicillata* and *Prionailurus viverrinus* are the top carnivores in the Godavari mangrove wetland. They enter aquaculture farms, resulting in a conflict between aquafarmer and wildlife. Resolving the conflict to conserve these vulnerable animals in the region is important, as they are highly threatened species in India (Sivakumar et al. 2017). Fishing cats are piscivorous and elusive, medium-sized cats weighing 8 and 17 kg, adapted to mangroves, swamps, wetlands, and riverine habitats, and are close relatives to the flat-headed cat (Sunquist and Sunquist 2002, Hunter 2019). The Andhra Pradesh Forest Department enumerated 70 fishing cats in 2012 (Malla and Sivakumar, 2014). Sathiyaselvam et al. (2016) reported 95-100 fishing cats in the Coringa Wildlife Sanctuary based on the pugmark, scat surveys, direct sightings and camera trapping methods. Malla (2016) estimated the density of fishing cats in the Coringa Wildlife Sanctuary (CWS) at 0.53 to 0.94 individuals per km^2, while Sathiyaselvam et al. (2016) calculated a density of 0.7 individuals per km^2 in the same period. More recently, Shameer et al. (2024) reported a fishing cat population of approximately 115 individuals in the Coringa Wildlife Sanctuary, with a density estimate of 0.40 ± 0.06 per km^2, which is lower than the densities reported by Malla (2016) and Sathiyaselvam et al. (2016). Two species of sponges, six species of jellyfish, 29 species of polychaetes, 21 species of crabs, 64 molluscs and 314 fish species are reported.

In the Godavari estuary, Rath et al. (2016) recorded a total of 19 species of penaeid and palaemonid prawns, representing nine genera and two families. They also consolidated a checklist comprising 49 prawn species from the Godavari estuary. Thirty-four mangrove-associated molluscan species from 14 families, with 28 gastropods and six bivalves, are reported. *Cerethidea cingulata* and *Assimenia nitida* are the most abundant species, while *Cerethidea obtusa* and *Telescopium telescopium* are the two most frequent species (Sivakumar et al., 2017). It is also a nesting site for migratory turtles, especially the endangered Olive Ridley and Green turtles.

Fauna in the Mangrove Wetlands

The Godavari River delta is one of India's most important bird areas (Islam and Rahmani 2004) with a documented inventory of 236 avifauna species, of which 88 are migratory. It is an important stopover point for migratory birds along the Central Asian Flyway. Endangered species, such as the White-backed and Long-billed Vultures, are reported (Sivakumar et al., 2014). These bird species exhibit seasonal fluctuations in their abundance, particularly in winter, when they migrate over the delta to feed on intertidal habitats and mudflats (Sathiyaselvam and Sreedhar, 2015). The reptiles like Gecko - *Hemidactylus* sp., *Psammophilus blanfordanus, Hemidactylus giganteus, Hemidactylus triedrus* and *Lygosoma albopunctata*, black-headed snake *Sibynophis subpunctatus*, common kukri –*Oligodon arnensis*, Earth snake- *Uropeltis ellioti*, and checkered keel-back *Xenochrophis piscator* are reported.

3.7. Hydrological Conditions

The Godavari delta is microtidal, with the mean tidal range in the southern parts of its branches never exceeding 1.5 m. Tides and surges do not propagate upstream of the Dowleswaram barrage. Water salinity ranges from 18 to 25 ppt throughout the year, and the pH ranges from 7.6 to 8.

3.8. Soil Properties

The Godavari sediments are characterised by mud, sandy clay, and clayey soil, with sandy clay soils predominating in the tail-end portions of the Godavari. A high density of mangrove population occurs in silty sediment environments. The pH of the estuarine sediments ranges from 7.4 to 7.9.

3.9. Land Use around the Mangrove Wetland

Paddy and coconut are the major crops grown in this area, with other crops, such as black gram and green gram also being cultivated. The Andhra Pradesh Forest Department planted *Casuarina* in the sandy areas in the Hope Island, near Masanitippa, and in Kandikuppa RF. *Neltuma* invasion is seen along the elevated areas of the delta. Salt pans are found near Uppalanka, Korangi, Balusutippa, and Chollangi villages. However, most of these salt pans are now abandoned. Shrimps, such as *Penaeus vannamei* and *P. monodon*, are cultured for their high market value in the Godavari delta. In 1990, the extent of shrimp farms was 2,118 hectares, which increased to 9,327 hectares by 2010. However, due to the outbreak of viral diseases, the area was reduced to 5,830 hectares in 2010, which again increased to 14,578 hectares after the introduction of *P. vannamei* in the Godavari delta during the early 2010s (Table 10). The estimated production from shrimp farms in 2021 was 180,000 tonnes. These shrimp farms are situated on private and revenue lands adjacent to mangrove areas.

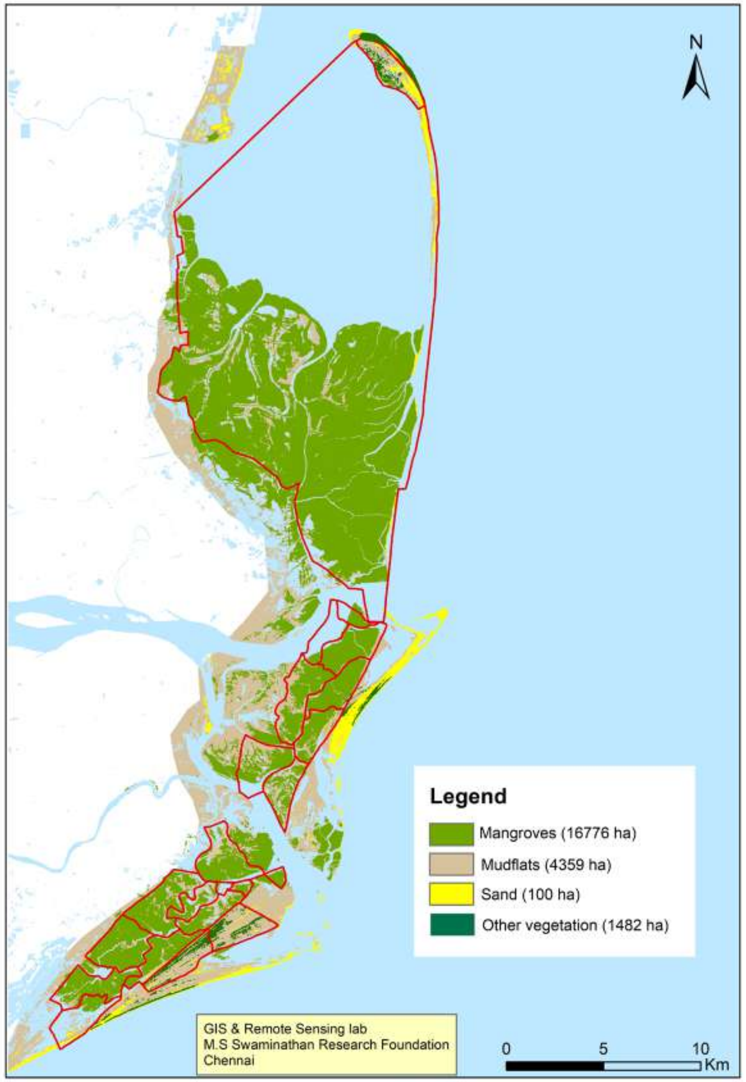
Table 10: Extent of shrimp farms in the Godavari Delta between 1990 and 2023

S. No.	Assessment Year	Extent of Aquaculture in Godavari Estuary (ha)
1	1990	2118
2	2000	9327
3	2010	5830
4	2023	14578

3.10. Land Use and Land Cover Change in the Godavari Mangrove wetlands

The land use and land cover (LULC) maps were prepared by classifying LANDSAT satellite imagery with a spatial resolution of 30 meters using a supervised classification technique called random forest algorithm. Satellite images of 1990, 2000, 2010 and 2023 are used for the assessment. The Random Forest algorithm, an ensemble learning technique, was employed due to its robustness and higher accuracy in classifying land cover types (Belgiu and Drăguţ, 2016). It utilises multiple decision trees to mitigate overfitting and enhance classification performance. Key spectral bands—Near Infrared (NIR), Red, and Green—were used to distinguish between mangroves, mudflats, sand, and other vegetation.

The extent of mangroves in the Godavari mangrove wetland increased from 16,776 hectares in 1990 to 20,227 hectares in 2023 (Figs. 20, 21 & 22). In 2000, the mangrove extent was approximately 18,306 hectares; by 2010, it had increased to about 18,329 hectares. The extent of mangroves in the Godavari wetland in 2003 was 16,406 hectares (Ramasubramanian et al., 2006). The significant increase in mangrove cover occurred between 2010 and 2023, highlighting the success of mangrove restoration by the Andhra Pradesh State Forest Department (APFD) and M S Swaminathan Research Foundation (MSSRF). The natural regeneration in the newly formed mudflats along the Kakinada Bay also contributed to the increase in the mangrove extent (Ramasubramanian et al., 2023). The local community's dependence on mangroves for firewood and timber has been substantially reduced due to the availability of alternative energy sources, such as LPG gas stoves. Similarly, the feral cattle population, which numbered approximately 5,000 during the early 1990s, has been significantly reduced.



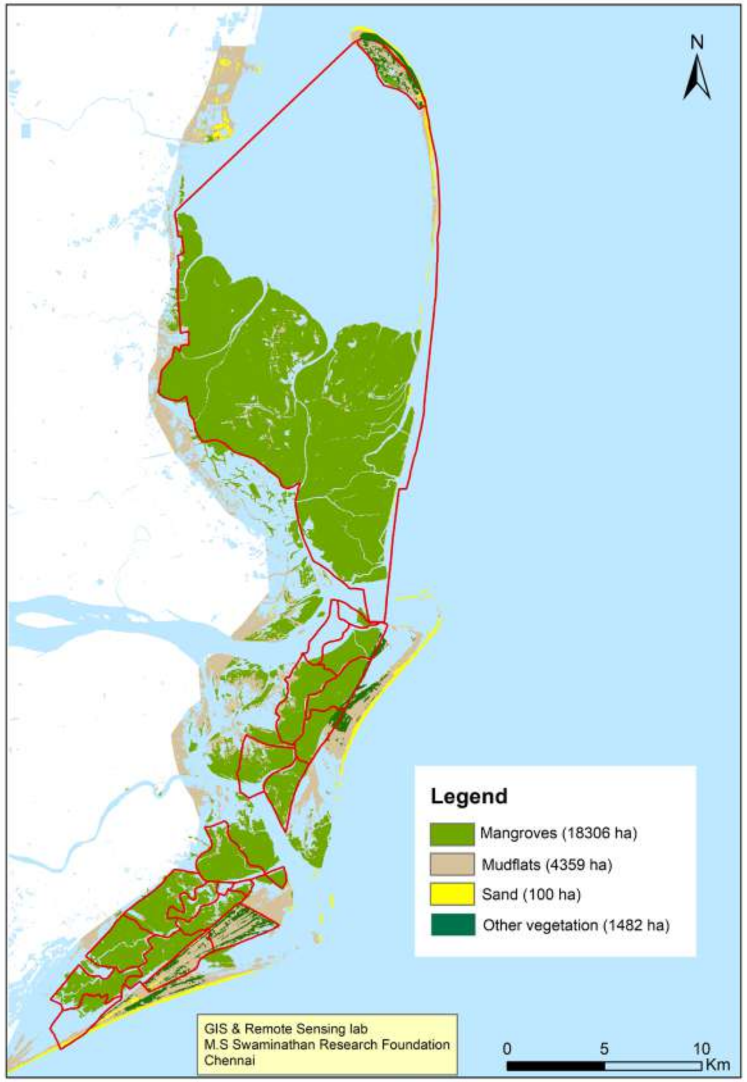
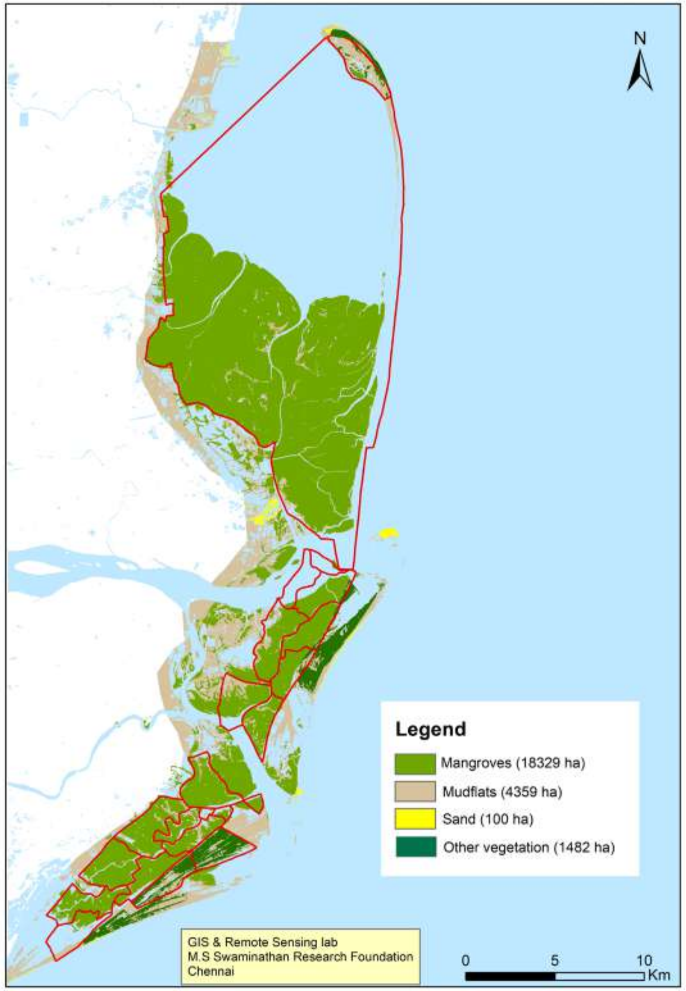


Figure 20: Land Use and Land Cover - Godavari Mangroves in 1990 (Left) and 2000 (Right)



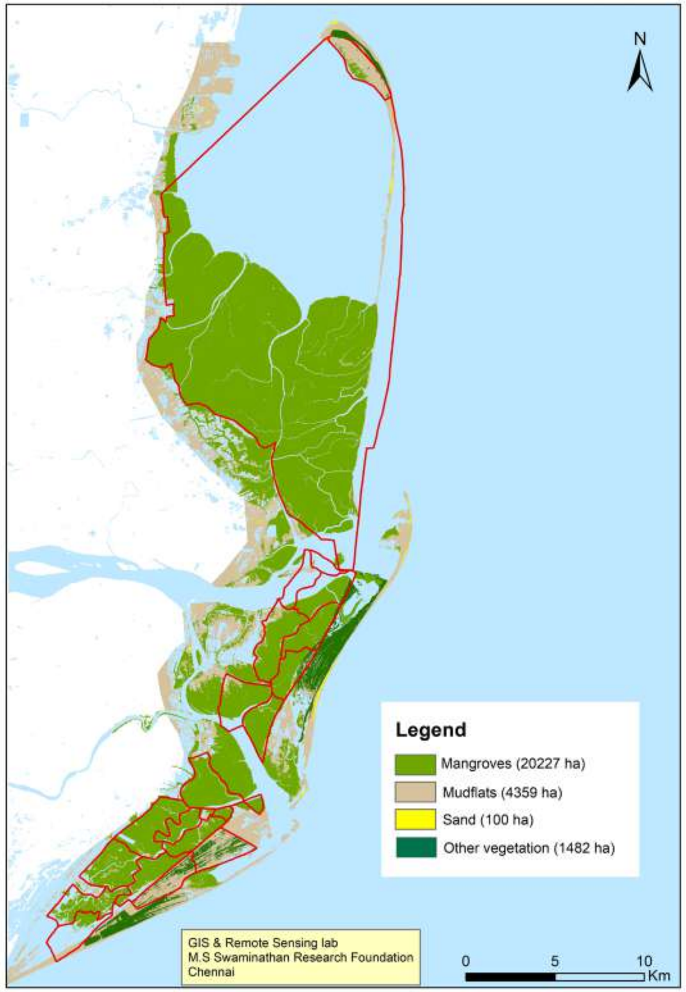


Figure 21: Land Use and Land Cover - Godavari Mangroves in 2010 (Left) and 2023 (Right)

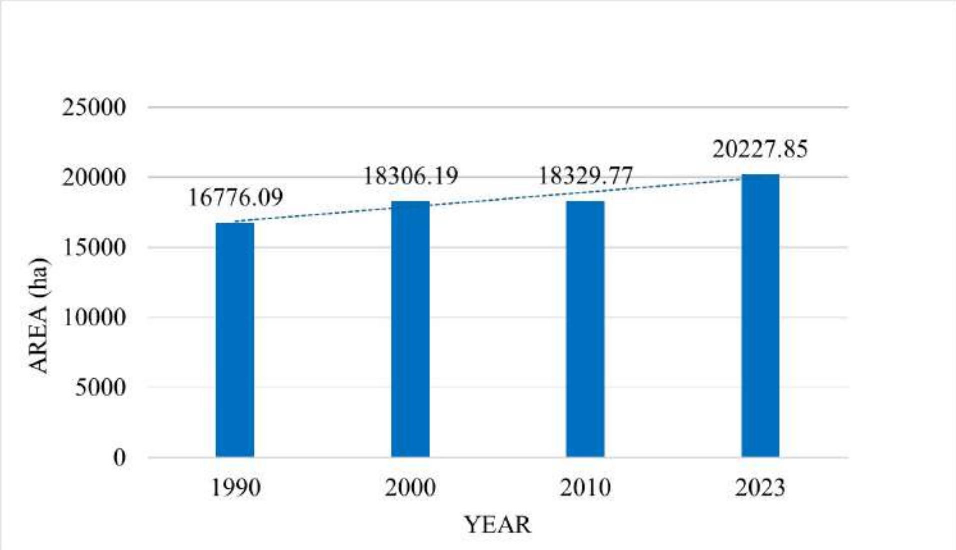


Figure 22: Extent of mangroves between 1990 and 2023 in the Godavari wetland

Substantial growth in mangrove cover occurred between 2010 and 2023, culminating in a total mangrove extent of 20,227 hectares. This upward trend highlights the effectiveness of restoration efforts and protection measures. A considerable extent of mangroves is present outside the Reserve Forest, which needs to be protected (Table 11). These mangroves are mostly established in the abandoned shrimp ponds.

Table 11: Extent of Mangroves inside and outside the Reserve Forest areas

Assessment Year	The extent of Mangroves inside the Reserve Forests (ha)	Extent of Mangroves outside the Reserve Forests (ha)	Total mangroves (ha)
1990	14,839	1,937	16,776
2000	16,547	1,758	18,305
2010	16,410	1,919	18,329
2023	16,783	3,444	20,227

3.11. Shoreline changes in the Godavari wetland

Shoreline changes were assessed using the Digital Shoreline Analysis System (DSAS) integrated with ArcGIS (Kallepalli et al., 2017). The study analysed spatiotemporal variations in shoreline positions using digitised Landsat satellite images from 1990, 2000, 2010, and 2023. After digitising the shoreline positions, a baseline was established inland and aligned parallel to the general coastal orientation. This baseline served as a consistent reference line for measuring shoreline changes and was carefully positioned to minimise distortion and maintain a uniform distance from shoreline features.

The digitised shorelines and baseline are then imported into the DSAS toolbar within ArcGIS. DSAS generated a series of regularly spaced, perpendicular transects extending from the baseline towards the coastline. These transects intersected the shorelines at different time intervals, allowing for the observation of shifts in the coastline over the study period. DSAS computed several statistical parameters to quantify the rate of change in the shoreline, including the End Point Rate (EPR), Linear Regression Rate (LRR), and Net Shoreline Movement (NSM). These metrics provided valuable insights into erosion and accretion patterns along the coastal zones of Godavari and Krishna mangrove wetlands.

The shoreline changes along the Godavari mangrove wetland from 1990 to 2023 showed more erosion than accretion since the long coastline from the Godavari River mouth near Bhairavapalem to Hope Island is exposed to severe wave action coupled with seawater currents (Figs. 23 & 24). The negative values (-61 to 0 m/decade) indicate erosion due to severe longshore littoral currents, reduced sediment supply, sea level rise, and extreme events such as cyclones. When the sediment supply through the river decreases, coupled with rising sea levels and land subsidence, it results in coastal erosion. Malini and Rao (2004) assessed coastal erosion and habitat loss along the Godavari delta using multi-temporal satellite sensor data and historical maps. The study revealed a loss of approximately 1,836 hectares of land along the Godavari delta between 1976 and 2001. This coastal erosion resulted in the displacement of local communities and the destruction of mangrove habitats. The study also revealed that the annual sediment transported by the river declined significantly, from 145.26 million tons in 1971-1979 to 56.76 million tons in 1990-1998. Numerous studies on deltas worldwide have shown that dam construction disrupts sediment flow, contributing to coastal erosion. In the estuarine region, erosion along the banks is noticed due to monsoon floods. Positive values (0 to 90 m/ decade) represent accretion, where the shoreline has advanced seaward, likely due to sediment deposition, favourable tidal actions, or changes in river discharge patterns. The southern sides of both the river mouths showed accretion. Over the years, the areas within the Kakinada Bay have showed more accretion.

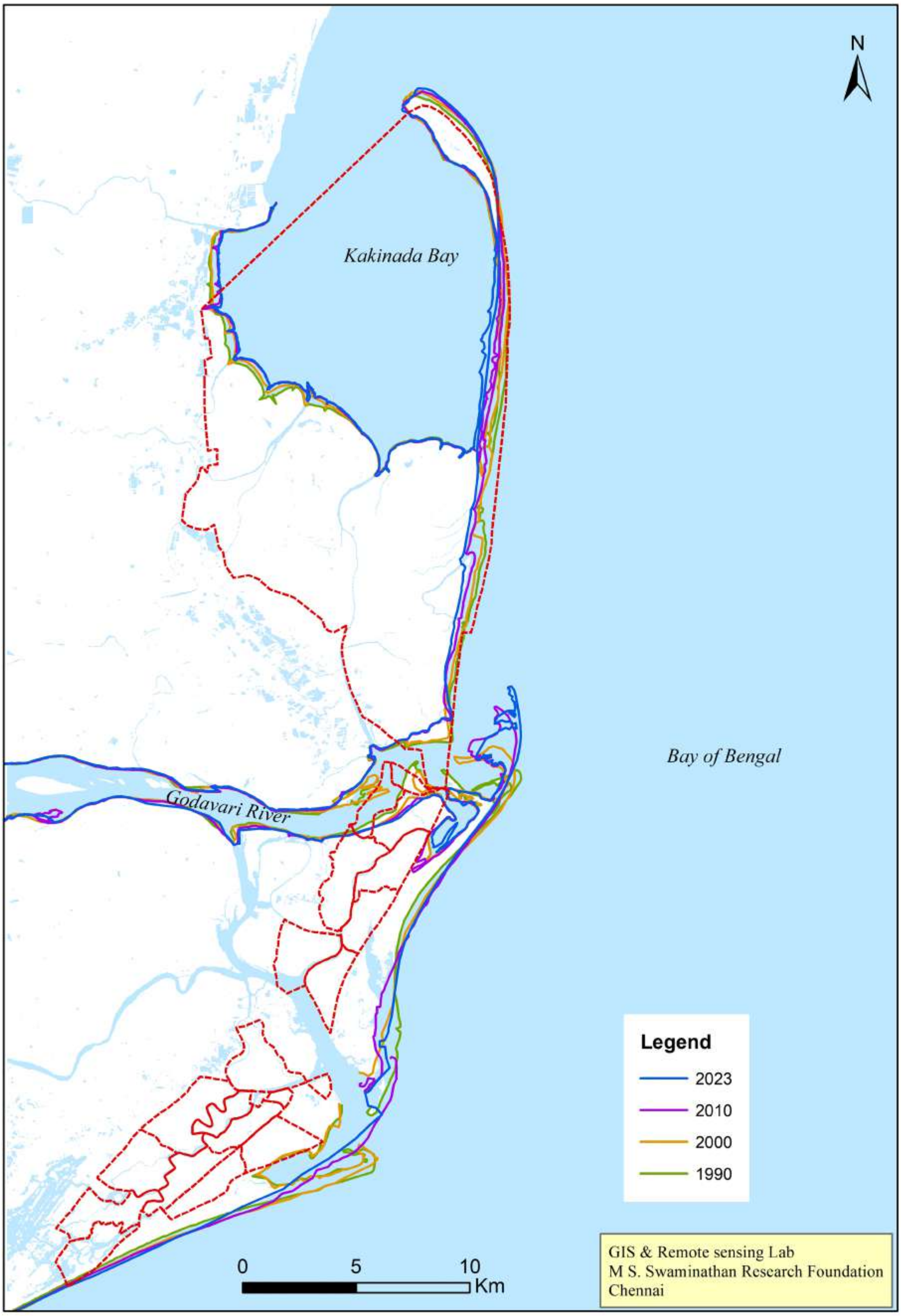


Figure 23: Shoreline of the Godavari coast from 1990 to 2023

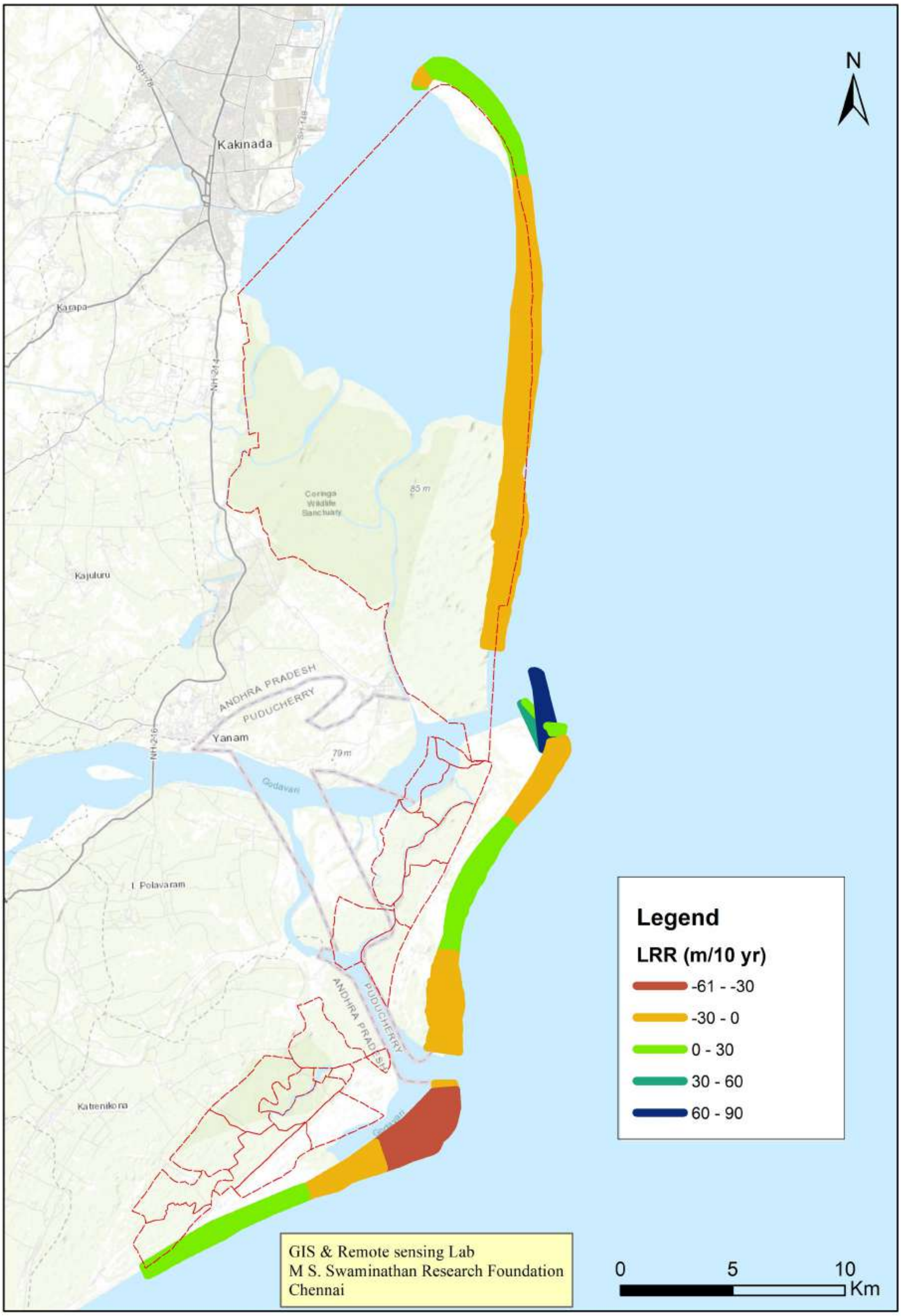


Figure 24: Shoreline changes in the Godavari coast from 1990 to 2023

3.12. Decadal changes in the Mangrove Cover in the Godavari wetland between 1990 and 2023

Mangrove wetlands are dynamic and influenced by natural processes, human activities, and environmental factors, resulting in both gains and losses in extent. From 1990 to 2023, the mangrove extent was analysed and extracted using LULC-classified images from the LANDSAT series using supervised classification. Changes in mangrove cover were mapped for each decade, categorising areas such as pristine (existing), newly formed, and degraded mangroves to track their spatial and temporal variations.

3.12.1. Changes between 1990 and 2000

The extent of the Godavari mangrove wetland showed a net increase of 1,530.1 hectares between 1990 and 2000. An area of about 2,737.71 hectares has been increased due to natural regeneration in the newly formed mudflats and the restoration of degraded areas. In comparison 1,207.61 hectares were lost mainly due to shoreline erosion (Fig. 25). The other drivers of mangrove loss are the conversion of inland mangrove areas for shrimp farming and other land uses.

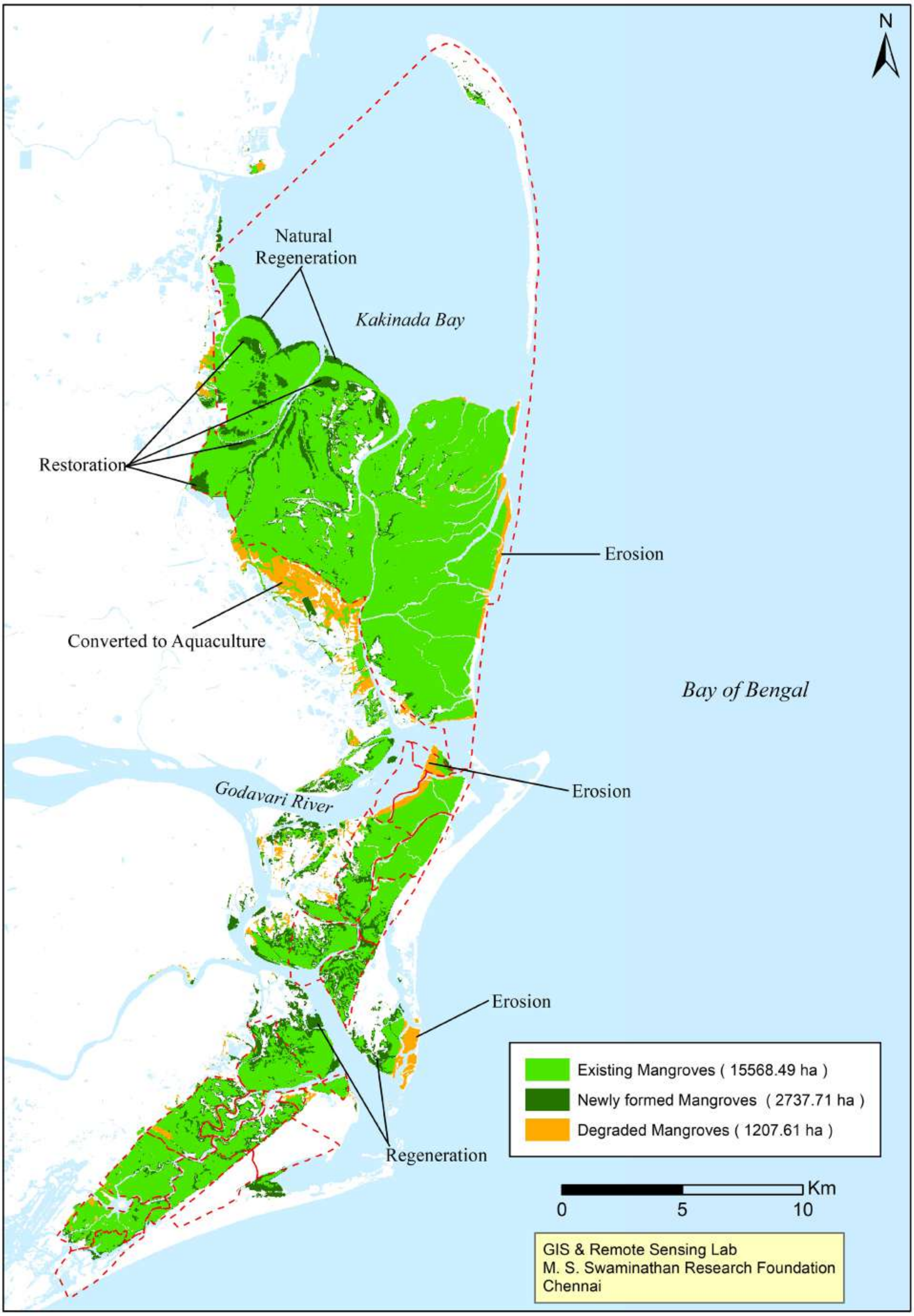


Figure 25: Change in Mangrove Cover between 1990 and 2000

3.12.2. Changes between 2000 and 2010

The changes in the mangrove cover between 2000 and 2010 showed a slight net loss of 23.58 hectares in the mangrove area. The mangroves' degradation accounted for 913.71 hectares, while mangrove cover growth contributed 874.59 hectares (Fig. 26). The degradation of mangroves was mainly due to shoreline erosion along the Bay of Bengal. However, mangrove restoration in the degraded areas and natural regeneration along the newly formed mudflats almost compensated for the loss.

3.12.3. Changes between 2010 and 2023

The changes in the mangrove cover between 2010 and 2023 showed a net increase of 1,898.08 hectares (Fig. 27). The mangrove extent increased due to mangrove restoration and the natural growth of mangroves. The mangrove cover increased by 2,869.46 hectares, while the loss of mangroves was 644.43 hectares due to shoreline erosion and aquaculture expansion (Fig. 28).

Over the 33 years, despite intermittent losses, the overall trend in the Godavari region was positive, with a total net increase of 3,716.01 hectares in mangrove cover. This increase in mangrove cover is due to favourable environmental conditions and effective conservation measures, including better protection from felling and grazing by the local community. Increasing mangrove cover helps minimise climate change-associated impacts, such as cyclones and sea level rise. However, persistent threats such as shoreline erosion, aquaculture development on revenue and private lands abutting the reserve forest boundaries, and the impacts of climate change require continued long-term monitoring to safeguard this mangrove wetland.

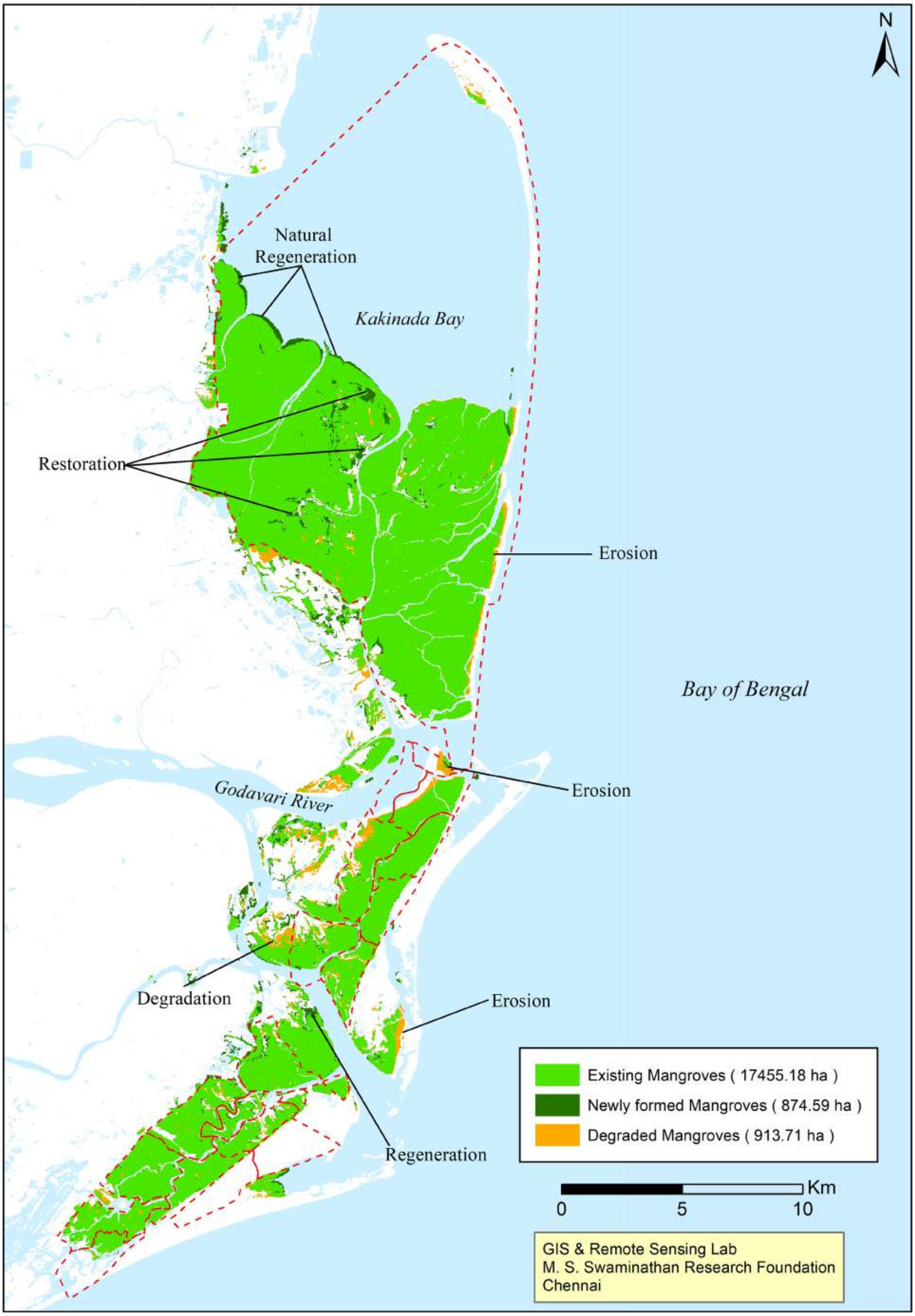


Figure 26: Change in Mangrove Cover between 2000 and 2010

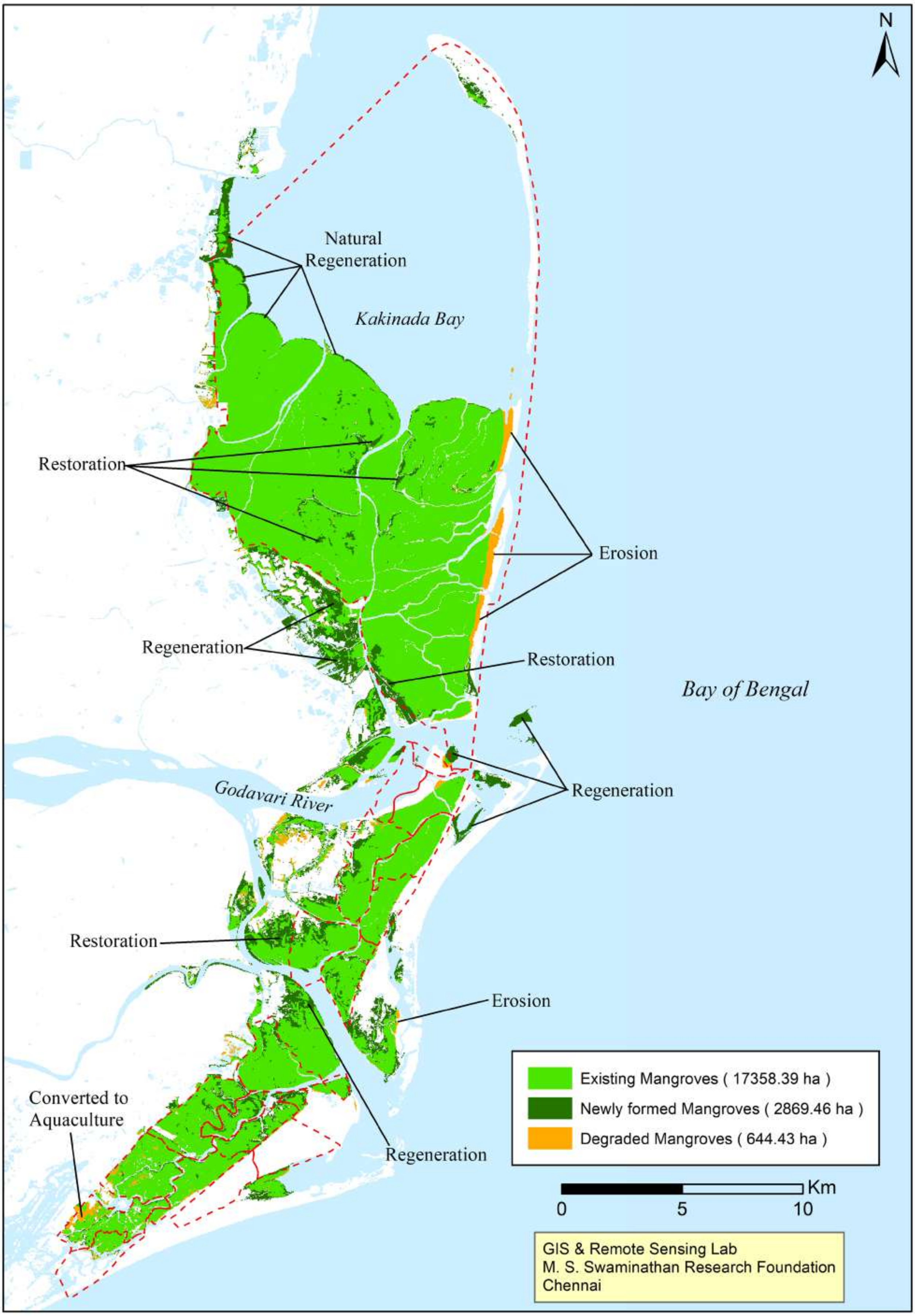


Figure 27: Change in Mangrove Cover between 2010 and 2023

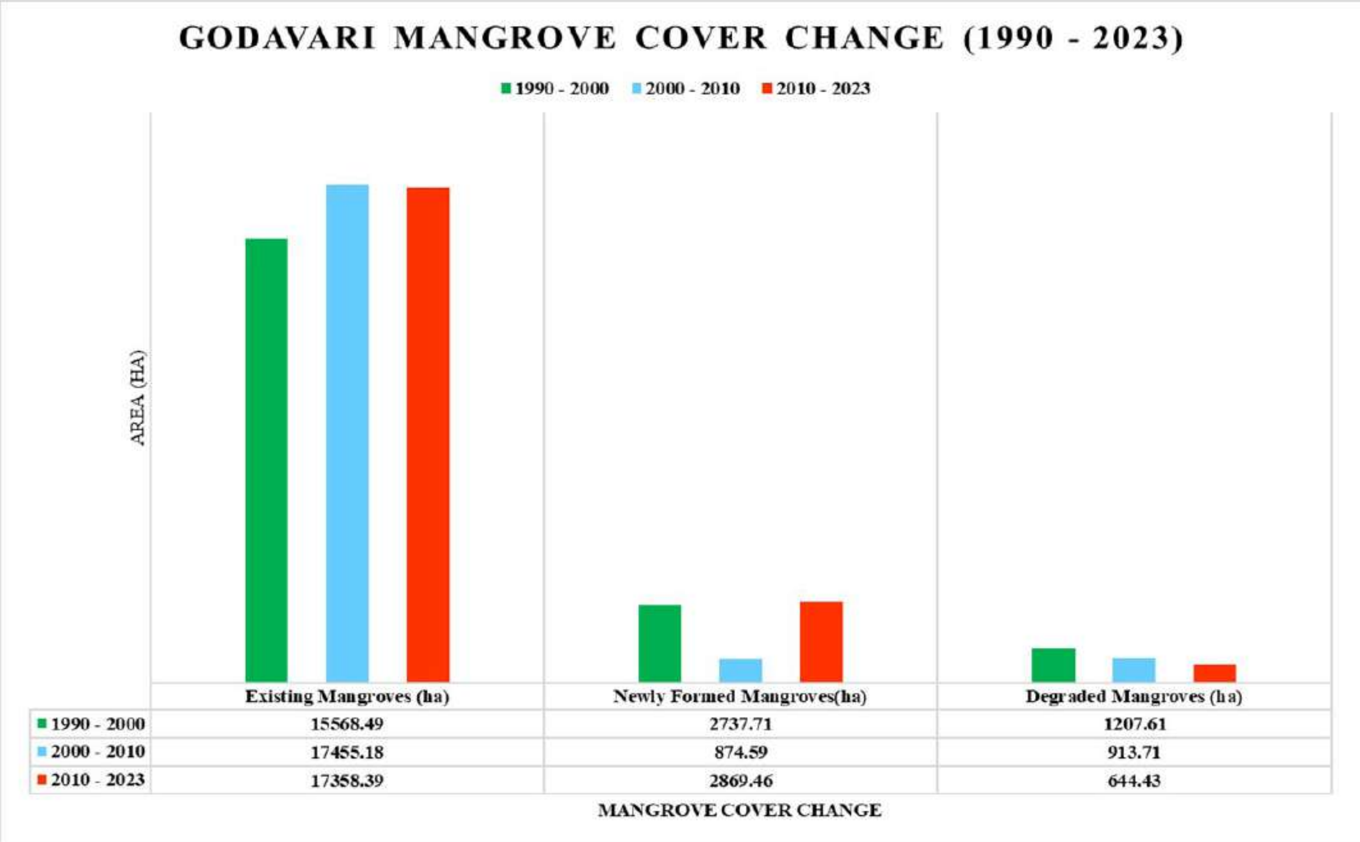


Figure 28: Change in Mangrove cover between 1990 and 2023

3.13. Dependency on the Godavari Mangroves

Local fishermen and farming communities depend on mangroves for fuel, firewood, fodder for cattle, timber and grass for thatching roofs. Mangroves play a crucial role in coastal fisheries production, with fishermen's communities in 44 villages utilising mangroves for subsistence fishing (Fig. 29). In 2019-2020, the total marine fish production was 37.27 lakh tonnes, with Andhra Pradesh contributing 5.64 lakh tonnes. The Godavari estuary is rich in bivalve resources, including *Perna viridis, P. indica, Meretrix meretrix, Anadara granosa, Katelysia opima, Placenta placenta*, and other gastropods such as *Telescopium* sp. The traditional fishing communities living near Chollangi creek collect molluscan shells in the Kakinada Bay and nearby creeks during low tide. They also harvest crabs and fish for their livelihood. Their traditional boat, the Shoe Dhoni (boat like a shoe), serves as their home for nearly six months of the year. They are migrants from Balusutippa, located 50 kilometres south of Kakinada Town. In the 1980s, the shoe boats numbered between 300 and 500; now, fewer than fifty remain. The decline is attributed to reduced market opportunities and restrictions imposed by the Wildlife Act, enforced by the Forest Department. The Coringa mangroves host various crustaceans, including *Penaeus indicus, P. monodon, P. semisulcatus, P. merguiensis* and *Metapenaeus affinis*. The bark of *Ceriops decandra* was used for colouring (dyeing) fishing nets in the past. Now, usage has decreased as they are using nylon nets.

Ecosystem services - Livelihood for small artisanal fishermen

The farming community in Chollangipeta, Ravimeraka, Polekurru, Mallavaram, and Tallarevu depends on mangrove forests for cattle grazing. All these cattle are feral (semi-domesticated) and live in the mangrove wetland throughout the year. *Porteresia* grass and *Avicennia* twigs are used as fodder for stall-feeding. Goats from nearby villages graze along the fringes. Grazing pressure has decreased drastically in recent years. During the late 1990s, the feral cattle population was at a high level. The forest department significantly reduced the numbers by providing high-yielding stall-fed buffaloes. The community also felt very uncomfortable fetching milk from the mangrove wetland.

The dependency on firewood has also decreased appreciably due to the use of LPG gas stoves. Until 2000, nearly all the nearby villagers relied on mangroves for firewood. The dependency of fishing hamlets on firewood was high due to their proximity to the mangroves. *Avicennia marina, Aegiceras corniculatum*, and *A. officinalis* are the preferred species for firewood. Similarly, in a few villages, women practised smoking of fish and prawns as a preservation method to enhance the shelf life. Firewood, often mangrove wood, was used to dry them. However, only a few families are now practising smoking fish using improved kilns. The timber from *Excoecaria agallocha, Bruguiera cylindrica, Avicennia marina*, and *A. officinalis* is used for house construction. Following the 1996 cyclone and the 2004 Indian Ocean tsunami, the cutting of mangrove wood for house construction has decreased as many fishermen's families have constructed concrete houses with the assistance of the government and other aid agencies.

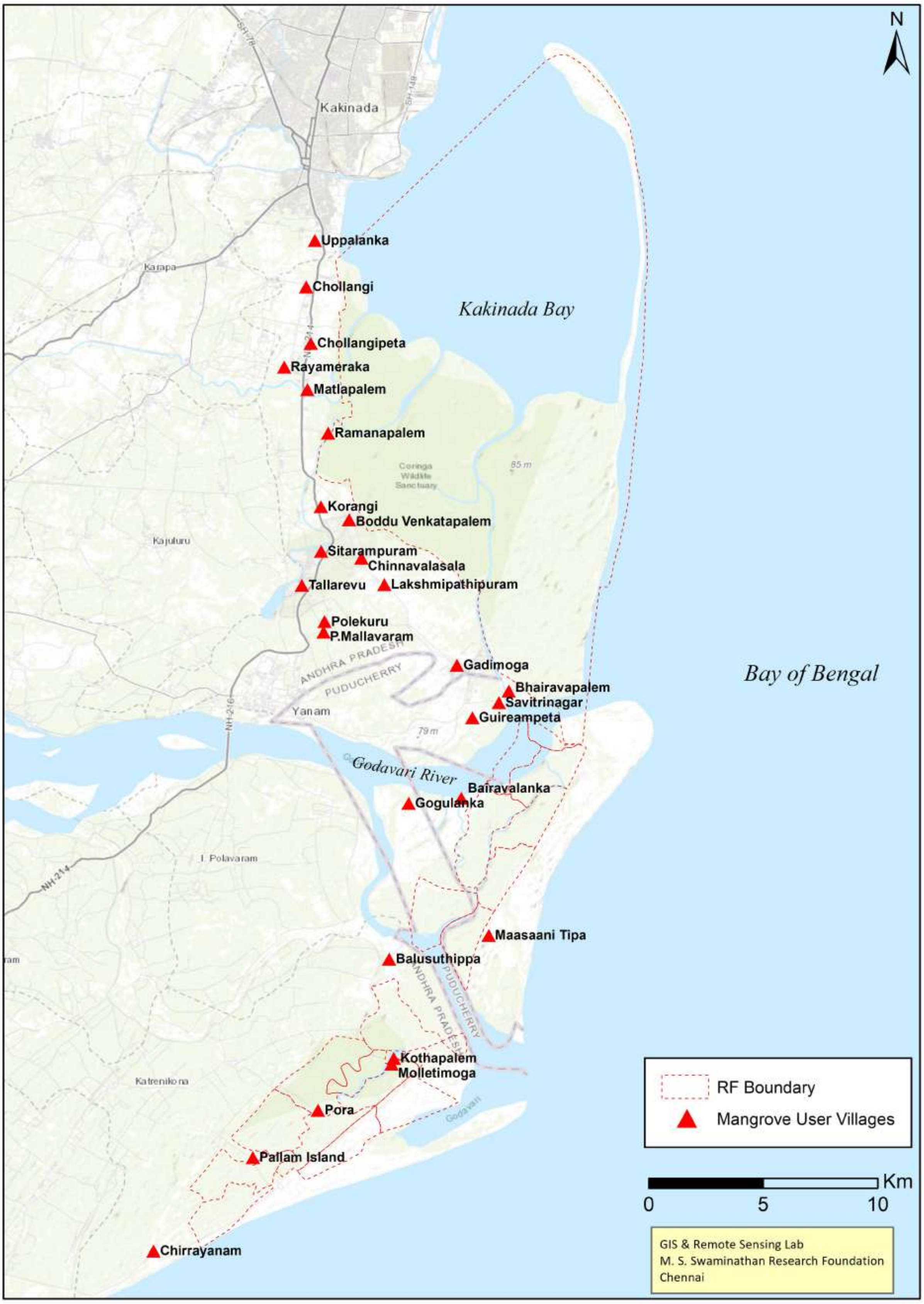


Figure 29: Mangrove Dependent Villages in the Godavari Wetland

Chapter 4: **Mangrove Wetlands in the Krishna Estuary**

Chapter 4: Mangrove Wetlands in the Krishna Estuary

4.1. Geo-Morphology

The Krishna Delta is one of India's most fertile and geomorphologically dynamic deltas. It has formed through the deposition of sediments carried by the Krishna River. The deltaic plain is divided into two distinct zones: the upper and the lower deltaic plain. The upper delta is older, located inland and composed of mature alluvium with well-drained soils. In contrast, the lower delta is younger, low-lying, and more susceptible to seasonal flooding. This zone includes mangroves, salt marshes, brackish water bodies, and tidal flats, reflecting ongoing sedimentation and active geomorphic processes. A prominent geomorphological feature of the Krishna Delta is its extensive network of distributaries, which are constantly evolving due to sediment deposition and channel migration. These processes contribute to the development of new deltaic lobes and the formation of paleochannels. Along the coast, the delta exhibits beach ridges and coastal sand dunes, shaped by a combination of wave energy and wind action. These landforms provide evidence of historic shoreline shifts and the delta's gradual outward progradation. The southern portion of the delta is characterised by backwaters and tidal lagoons, where saline and brackish conditions support the growth mangroves. The delta's sediments primarily consist of fine silt, clay, and sand, originating from the Western Ghats and transported downstream by the Krishna River. The River Krishna, before joining the Bay of Bengal, divides into four branches. The northernmost branch, Hamsaladevipaya, originates near Avanigadda and enters the sea in a southeast direction. Further south, the river splits into three additional branches, all of which flow south and join the Bay of Bengal (Fig. 30). The construction of dams upstream and the expansion of irrigation infrastructure have disrupted the river's natural flow, reducing the sediment supply to coastal areas. These changes have led to coastal erosion, land subsidence, and the degradation of wetland habitats.

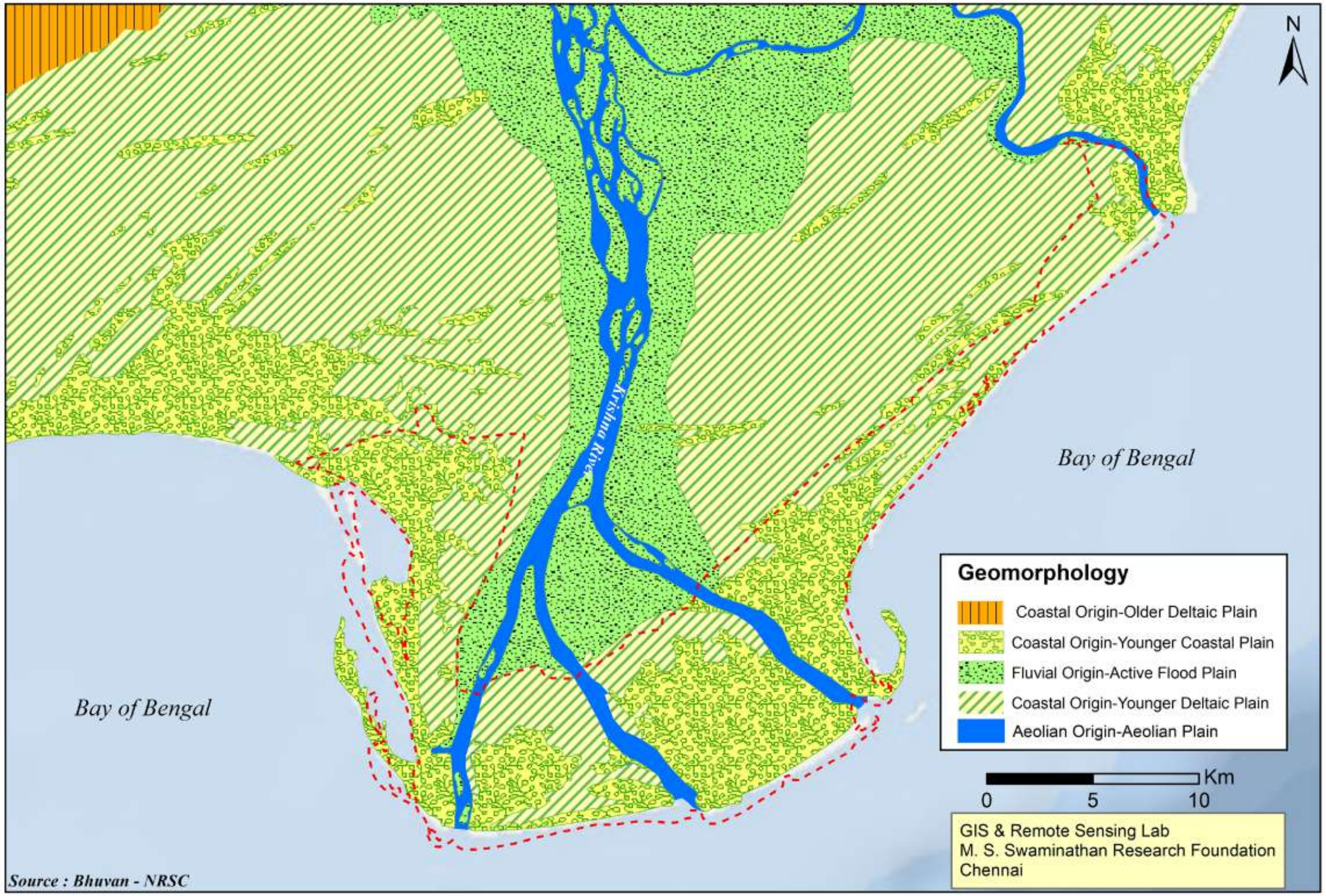


Figure 30: Geo-morphology map of the Krishna wetland

4.2. Reserve Forests in the Krishna Wildlife Sanctuary

The Krishna mangrove wetland is situated in the coastal plains of the Krishna delta. The extent of Krishna Wildlife Sanctuary (Lat. 15°46'27"N; Long. 80°56'39"E) is 194.81 km^2 spread over four administrative mandals: Koduru and Nagayalanka in Krishna District, and Repalle and Nizampatnam in Bapatla District, Andhra Pradesh. The backwaters of the Bay of Bengal provide an appropriate ecosystem and refuge for fish, marine invertebrates, and birds. The climate is generally hot and dry, with maximum temperatures rising to 45°C in May and dropping to 18°C in December. The mean annual rainfall in the Krishna mangrove wetland is 784 mm. The southwest monsoon rainfall sets in around the middle of June and ends by the middle of October. Nearly 70% of rainfall occurs between July and September, and about 20% of rainfall occurs during the northeast monsoon season. The Krishna Wildlife Sanctuary was initially notified as a wildlife sanctuary in G.O.No.211 EFS&T. (For. Department), dated 26.06.1989. However, it was officially declared as the Krishna Wildlife Sanctuary under Section 26-A of the Wildlife (Protection) Act, 1972, via G.O. Ms No. 79, Environment, Forests, Science and Technology (For.-III) Department, dated 27.06.1998, and it was published in the Andhra Pradesh Gazette No. 343 on 22.07.1998. It is surrounded by the Bay of Bengal to the east, south, and west, with the northern side bordered by the geographical area of the Bapatla and Krishna districts. The Government of India notified an Eco-Sensitive Zone with an extent of 1 kilometre surrounding the boundary of the Krishna Wildlife Sanctuary, in Krishna and Bapatla districts, under the Environment (Protection) Act, 1986. The area of the Eco-Sensitive Zone is 175.33 km^2.

The Krishna Wildlife Sanctuary consists of Sorlagondi Reserve Forest (RF), Sorlagondi Extension Reserve Forest, Nachugunta RF, Yelichintaladibba RF, Molagunta RF, Kothapalem RF, and Lankevanidibba RF (Fig. 31; Table:12). A total of 39 species, including 17 true mangrove and 22 mangrove associate species, occur in the Krishna mangrove wetland.

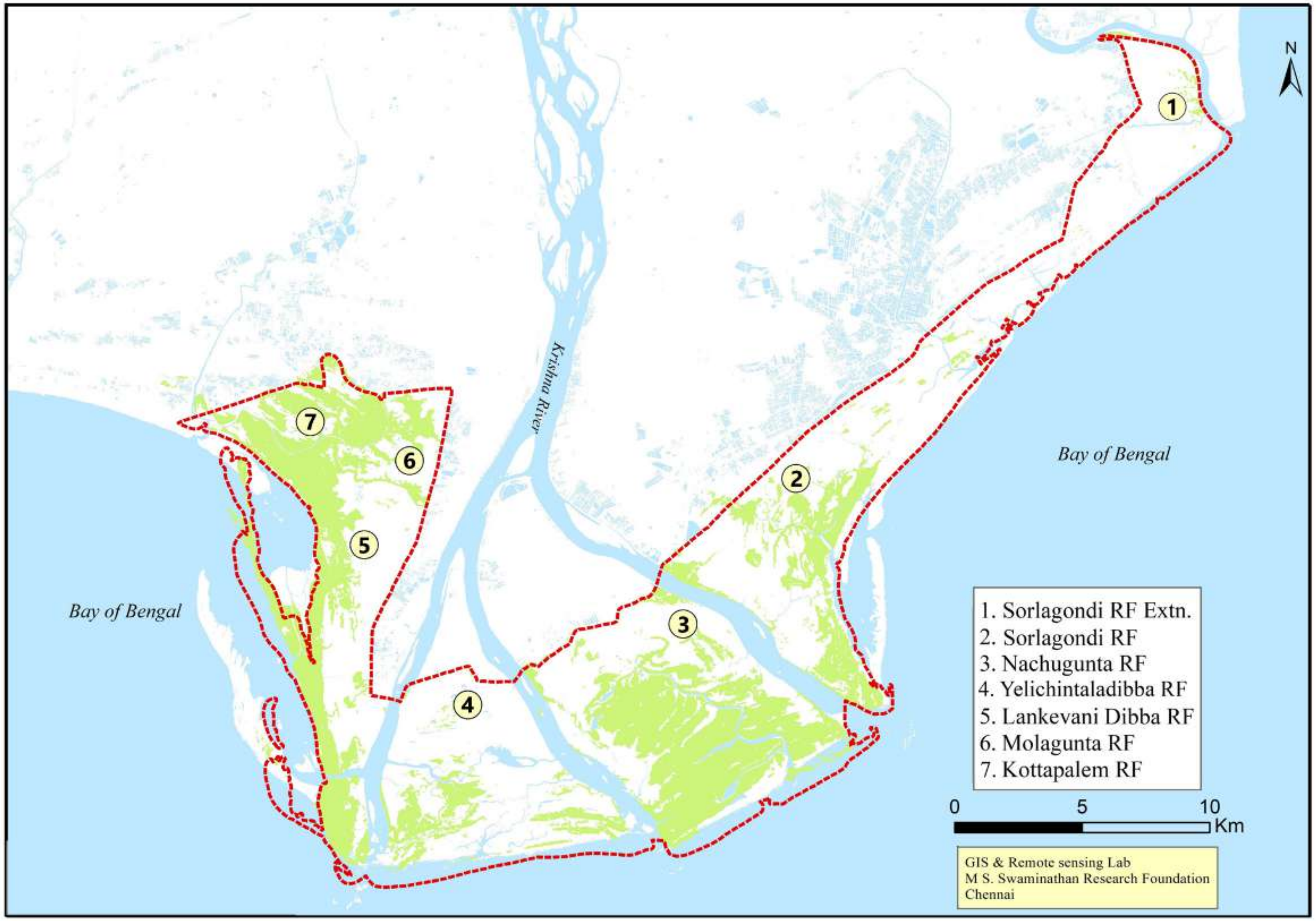


Figure 31: Reserve Forests in Krishna the Wildlife Sanctuary

Table 12: Reserve Forest Areas in the Krishna Wildlife Sanctuary

S. No.	Name of the District	Name of the Mandal	Name of the Reserve Forest	Extent (in ha.)
1	Bapatla	Repalle and Nizampatnam	Kothapalem RF – Bit No.1	1553.91
2			Molagunta RF	1736.20
3			Lankevanidibba RF	1153.36
4	Krishna	Koduru and Nagayalanka	Yelichintaladibba RF	3714.09
5			Nachugunta RF	6064.64
6			Sorlagondi RF	2508.22
7			Sorlagondi Extn. RF	2691.18

4.3. Flora of the Krishna Wetland

The Krishna mangrove wetland has four distributaries and a network of creeks supplying tidal water for the growth of mangroves. The mangroves on the landward side have *Acanthus ilicifolius, Aegiceras corniculatum, Avicennia officinalis, A. marina, Excoecaria agallocha*, and *Lumnitzera racemosa. Aegialitis rotundifolia, Bruguiera cylindrica, B. gymnorrhiza, Ceriops decandra, C. tagal, Rhizophora apiculata, R. mucronata, Xylocarpus* spp., *Avicennia alba, Sonneratia apetala* and *Porteresia coarctata* are more on the seaward side. The halophytes, namely *Salicornia brachiata, Sesuvium portulacastrum, Suaeda fruticosa, S. maritima, S. nudiflora*, and *Tecticornia indica*, are found along with stunted *Excoecaria agallocha* and *A. marina* in the elevated areas where the tidal water flow is occasional. Dense *Neltuma juliflora* is observed along the riverside upstream of Sorlagondi RF, Nachugunta RF, and Yelichintaladibba RF. The vegetation in Lankevanidibba RF is thick and diverse due to the increased fresh water discharge. Species like *Aegialitis rotundifolia* and *Ceriops tagal* are observed in the Nachugunta RF. The mangrove associates, namely *Volkameria inermis, Hibiscus tiliaceus, Salvadora persica, Thespesia populneoides, Caesalpinia crista, Dalbergia spinosa, Derris trifoliata, Ipomoea pes-caprae* and *I. tuba*, are also recorded in most of the reserved forests.

Mangrove health is better on the south-western side (Bapatla) of the estuary, as large areas of natural regeneration along the Bay of Bengal are observed. *Xylocarpus granatum* and *X. molluccensis,* along with *Rhizophora* spp., are found along the creeks of the Lankevani Dibba RF. The list of mangrove and mangrove-associated species is given in Table 13.

Table 13: List of mangroves and mangrove-associated species in the Krishna mangrove wetland

S. No.	Name of the Species and Family	Telugu name	Status
1	*Aegialitis rotundifolia* Roxb. Plumbaginaceae	-	Rare
2	*Avicennia alba* Bl. Acanthaceae	Vilava mada	Common
3	*Avicennia marina* (Forsk.) Vierh Acanthaceae	Tella mada	Common
4	*Avicennia officinalis* L. Acanthaceae	Nalla mada	Common
5	*Acanthus ilicifolius* L. Acanthaceae	Alchi	Common near the creeks
6	*Aegiceras corniculatum* (L.) Blanco Myrsinaceae	Guggilam	Common
7	*Bruguiera cylindrica* (L.) B. Rhizophoraceae	Urudu	Common
8	*Bruguiera gymnorrhiza* (L.) Savigny Rhizophoraceae	Kandriga	Common
9	*Ceriops decandra* (Griff.) Ding Hou Rhizophoraceae	Togara	Rare
10	*Ceriops tagal* (Perr.) C.B. Rob. Rhizophoraceae	-	Rare
11	*Lumnitzera racemosa* Wild. Combretaceae	Thanguda	Common on the landward side
12	*Excoecaria agallocha* L. Euphorbiaceae	Tilla	Common
13	*Rhizophora apiculata* Bl. Rhizophoraceae	Ponna	Common
14	*Rhizophora mucronata* Lamk. Rhizophoraceae	Ponna	Common
15	*Sonneratia apetala* Buch.-Ham. Lythraceae	Kalinga	Common near the river mouth
16	*Xylocarpus granatum* Koen. Meliaceae	Senuga	Rare
17	*Xylocarpus moluccensis* (Lamk.) M. Roem. Meliaceae	Senuga	Rare
Trees – Mangrove Associates			
1	*Volkarmeria inerme* Gaertn. Verbanaceae	Pisingi	Common along the creeks on the landward side
2	*Hibiscus tiliaceus* L. Malvaceae	Attakanara	Rare
3	*Salvadora persica* L. Salvadoraceae	Chekkara chettu	Rare
4	*Thespesia populneoides* (Roxb.) Kostel Malvaceae	Ganguravi	Rare
Climbers –Mangrove Associates			
1	*Caesalpinia crista* L. Caesalpiniaceae	Rachis	Common
2	*Dalbergia spinosa* Roxb. Fabaceae	Chillinga	Common
3	*Derris trifoliata* Lour. Fabaceae	Nalla theega	Common
4	*Ipomoea pes-caprae* (L.) Sweet Convolvulaceae	-	Common along the beachside

S. No.	Name of the Species and Family	Telugu name	Status
5	*Ipomoea tuba* (L.) Convolvulaceae	Tella teega	Common
6	*Sarcolobus carinatus* Wall. Asclepiadaceae	Balaboddu teega	Common
Grass			
1	*Aeluropus lagopoides* (L.) Trin. Poaceae	-	Common in degraded mangrove areas
2	*Fimbristylis ferruginea* (L.) Vah. Cyperaceae	-	Common near the river mouth
3	*Myriostachya wightiana* (Necs ex. Steud.)Hook.f. Poaceae	Dhaba gaddi	Common along the creeks on the landward side
4	*Porteresia coarctata* (Roxb.) Tateoka Poaceae	Yellugaddi	Common
Halophytes			
1	*Cressa cretica* L. Convolvulaceae	-	Common in degraded and elevated areas
2	*Heliotropium curassavicum* L. Boraginaceae	-	Common in degraded and elevated areas
3	*Salicornia brachiata* Roxb. Amaranthaceae	-	Common near the seaside
4	*Sesuvium portulacastrum* (Linn.) Linn Aizoaceae	-	Common in degraded and elevated areas
5	*Suaeda fruticosa* Forssk. ex J.F.Gmel. Amaranthaceae	Elakura	Common in degraded and elevated areas
6	*Suaeda maritima* (L.) Dumort. Amaranthaceae	Elakura	Common in degraded and elevated areas
7	*Suaeda nudiflora* (Willd.) Moq Amaranthaceae	Elakura	Common in degraded and elevated areas
8	*Tecticornia indica* (Willd.) K.A.Sheph. & Paul G.Wilson, (Syn *Arthrocnemum indicum)* Amaranthaceae	-	Common in degraded and elevated areas

4.4. Mangrove Species Zonation

Species-level zonation of mangroves was mapped using IRS LISS IV satellite imagery (5 m resolution). A supervised classification technique was applied based on spectral differences among species. In the Krishna mangrove ecosystem, three major mangrove zones, namely *Avicennia* sp., *Rhizophora* sp. and *Excoecaria agallocha*, are classified (Fig. 32).

Figure 32: Species-wise distribution in the Krishna mangrove forest

4.5. Density mapping in Krishna Mangroves (2023)

In the Krishna mangrove wetland, moderately dense mangroves dominate the landscape, covering approximately 10,534 hectares. The restoration of mangroves in the degraded areas and the natural regeneration of mangroves in newly formed areas contributed significantly to the moderately dense cover, indicating a mangrove ecosystem that is young and not yet fully mature. Open mangroves, the less dense, occupy around 2,302 hectares. Dense mangroves, representing well-established, comparatively old and tall mangrove vegetation, occupy an area of about 6,378 hectares (Fig. 33). The spatial distribution indicates that the Krishna delta supports substantial mangrove coverage, with dense areas found in the estuaries and along the tidal water creeks, where tidal water inundation is optimal, favouring mangrove growth.

Figure 33: Mangrove Canopy Density in the Krishna mangrove forest (2023)

4.6. Fauna in Krishna Wetland

Invertebrates are abundant in the mangrove wetlands and coastal waters of the Krishna estuarine region. Nearshore molluscs, where the salinity is high, the species such as *Mytilus indica, M. viridis, Crossostrea madrasensis*, and *Xancus psycum* are more abundant. In the low-salinity zones, species such as *Meretrix meretrix, Vellorita cyprinoides, Anadora granosa*, and *Katelysia spina* are abundant. Other molluscs, including *Ammusium, Pecten, Anadora*, and *Mecter*, are mostly found in marginal areas.

Mangrove swamps serve as crucial nursery grounds for shrimps and other crustaceans. The crustaceans in this area primarily consist of crabs and prawns. Notable crab species include the riddler crab *(Uca dussumieri)*, which is prevalent near the sea, as well as species such as *Scylla serrata, S. oceanica, S. trangubarica*, and *S. paramansina*, which dominate in mangrove wetlands. The nutrient-rich detritus of mangrove waters creates an ideal breeding environment for prawns and fish. Nine penaeid prawn species have been reported in the Krishna mangrove wetland, including *Penaeus indicus, P. monodon, P. semisulcatus, P. merguiensis, Metapenaeus dobsoni, M. monoceros, M. brevicornis, M. affinis*, and *Macrobrachium rosenbergii*. More than 90 species of avifauna have been reported. Interestingly, some migratory birds are exclusive to the Krishna delta mangroves and are absent in the Godavari mangroves.

The Krishna mangrove wetlands are home to a unique array of wildlife. Sightings of the smooth-coated otter (*Lutrogale perspicillata*) have been reported (Kantimahanti & Allaparthi, 2017), emphasising the need for conservation. Camera-trap studies in the Krishna Wildlife Sanctuary recorded 1,116 images, capturing species such as fishing cats, jungle cats (*Felis chaus*), golden jackals (*Canis aureus*), wild pigs (*Sus scrofa*), and monkeys. The Relative Abundance Index (RAI) showed golden jackals as the most frequent (36.74), while fishing cats (5.52) and jungle cats (2.19) were less common. Other mammals, including rodents, monkeys, and wild pigs, were observed at even lower frequencies. Fishing cats face significant threats from human activity, particularly conflicts arising from poultry predation (Chowdhury et al., 2015; Chakraborty et al., 2020). However, the comparative study showed fewer fishing cats (*Prionailurus viverrinus*) in the Krishna wetland than in the Godavari mangroves (Shankar et al., 2020).

4.7. Hydrological conditions

The maximum tidal amplitude is 1.2 m, and the minimum is 0.4 m in Sorlagondi RF during January 2024. However, the tidal variation is minimal during summer. Navigation of medium-sized fishing boats is difficult in small creeks on the landward side during low tide. The water temperature ranged from 28 to 31°C, and the pH ranged from 7.5 to 8.1, with salinity levels varying from 20 to 24 ppt in January 2024.

4.8. Soil properties

The soil of the Krishna mangroves is clayey. The major riverbeds – Gollalamatapaya, Nadimeru and Krishna – are found to be clayey rather than silt. The overall soil texture may be classified as silty clay. The soil salinity is higher in summer than in winter and rainy seasons due to the high evaporation rate during summer. The soil pH ranged from 7 to 8.8.

4.9. Land Use around Mangrove Wetland

The region comprises mangrove vegetation, mudflats, rivers, streams, canals and creeks, salt pans, aquaculture, and agricultural farms. Paddy is the dominant crop cultivated in this area. Other crops grown in this area include maize, green gram and black gram. The water utilised for agriculture is mainly from the Krishna River. *Casuarina* and *Eucalyptus* plantations are located along the coast near Sangameswaram, Pathaupakali, and Nali.

Aquaculture is being practised both in revenue lands and private lands. In some places, paddy fields have been converted to prawn farms; in others, the same farms have been reconverted to paddy fields. Tiger prawns and white-leg prawns are mostly cultured in aquaculture farms. The extent of shrimp farms adjacent the Krishna mangroves in 1990 was 7,896 hectares. In 2000, there was an exponential increase in the extent, reaching 26,988 hectares. However, the area has drastically reduced to 9,502 hectares in 2010 due to a viral disease outbreak. Again, the extent of shrimp farm area increased in 2023 to 13,774 hectares after the disease-resistant *Litopenaeus vannamei* had been introduced (Table 14). Krishna district is the largest shrimp-producing district in the country. The production in this area is 9,04,400 MT of inland fish, 1,93,084 MT of inland prawn and 2,14,765 MT of brackish water shrimp.

Table 14: Extent of Shrimp farms in the Krishna Delta between 1990 and 2023

Assessment Year	Extent of Aquaculture in Krishna Estuary (ha)
1990	7,896
2000	26,988
2010	9,502
2023	13,774

The Defence Research and Development Organisation (DRDO) Missile Test Range is being constructed at Gollalamoda village in Nagayalanka Mandal. It is a third missile testing range to support both short-range and long-range missiles. It is located on the fringe of the mangrove wetland. About 150 hectares of mangrove area have been used to construct this facility. DRDO supported large-scale mangrove plantations in the Krishna Wildlife Sanctuary to compensate for the loss.

4.10. Land Use and Land Cover Change in the Krishna Mangroves

The land use and land cover change in the Krishna mangrove wetland showed a substantial increase from 7,235 hectares in 1990 to 18,744 hectares in 2023 (Figs. 34, 35, 36 & 37). In 2000, the extent increased to 9,027 hectares from 7,235 hectares, reaching 12,708 hectares in 2010.

There is a significant increase between 2010 and 2023 (Fig. 38). This remarkable increase is attributed to the mangrove restoration efforts undertaken by the Andhra Pradesh State Forest Department (APFD) and the M.S. Swaminathan Research Foundation (MSSRF) in degraded mangrove areas as well as the natural regeneration in degraded areas, such as abandoned shrimp ponds, and the establishment of mangroves in newly formed mudflats in the vast regions of the wetland. Like the Godavari wetlands, the rural villages living near the Krishna mangrove wetland have substantially reduced their dependency on mangroves.

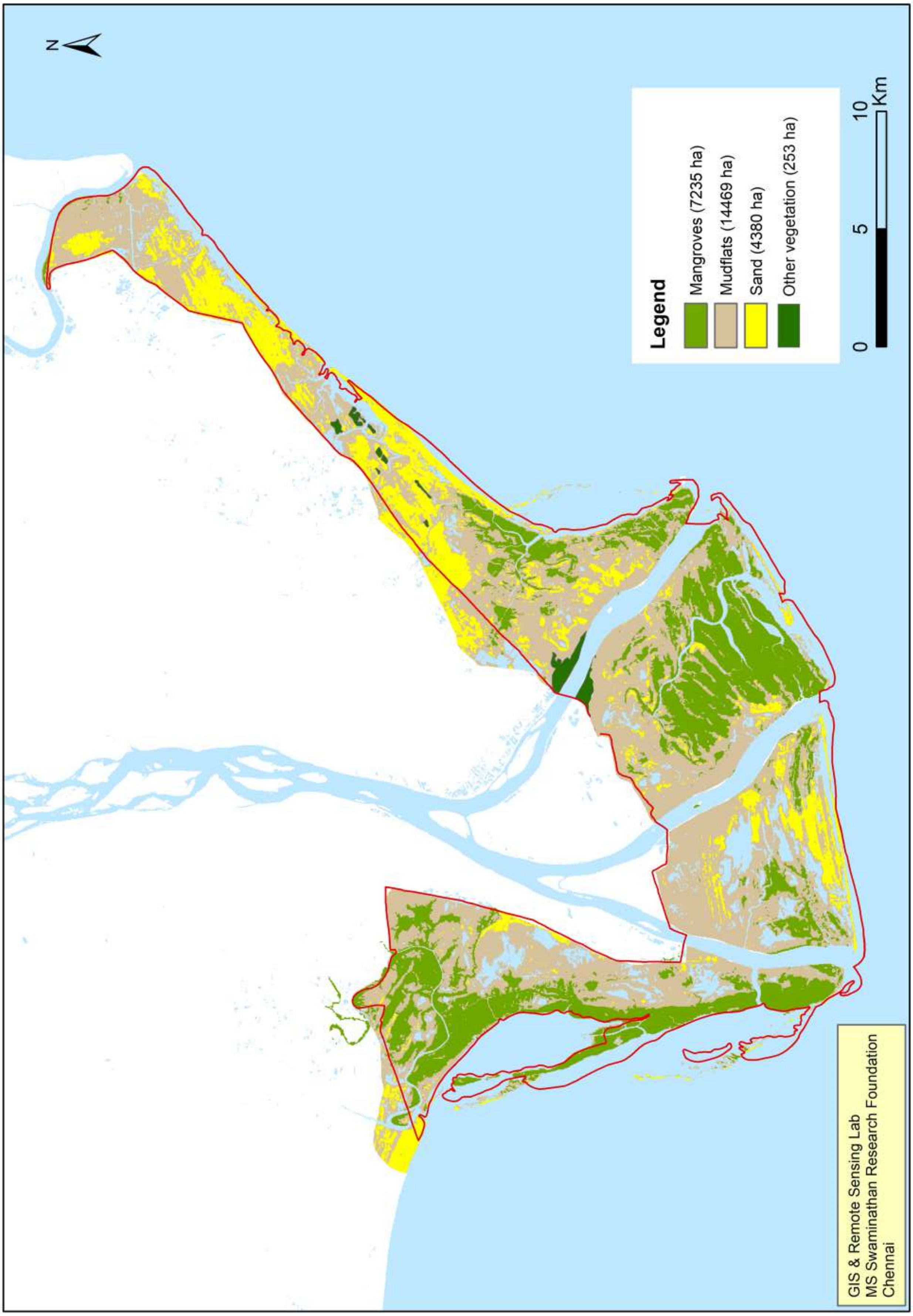


Figure 34: Land Use and Land Cover in 1990

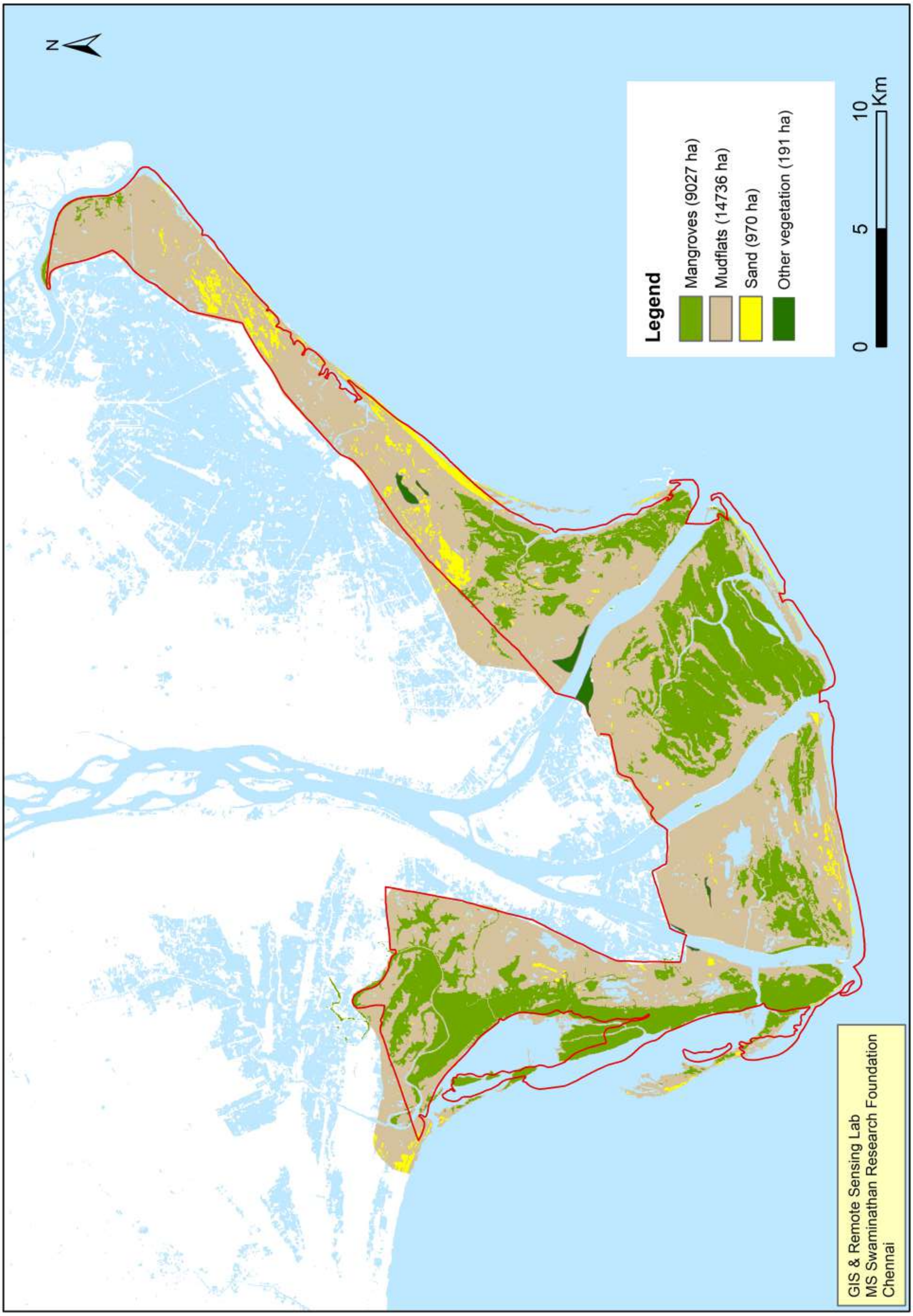


Figure 35: Land Use and Land Cover in 2000

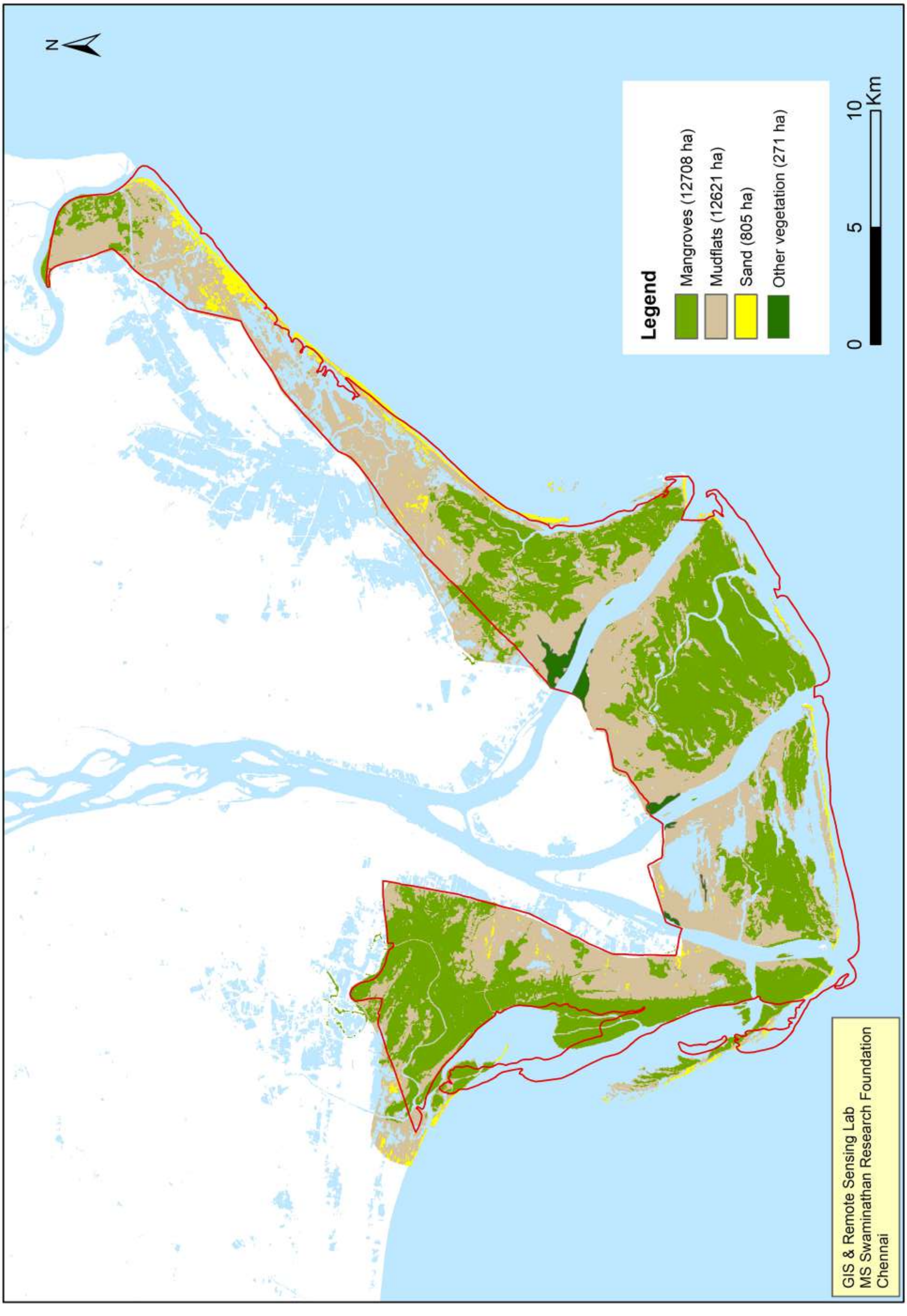


Figure 36: Land Use and Land Cover in 2010

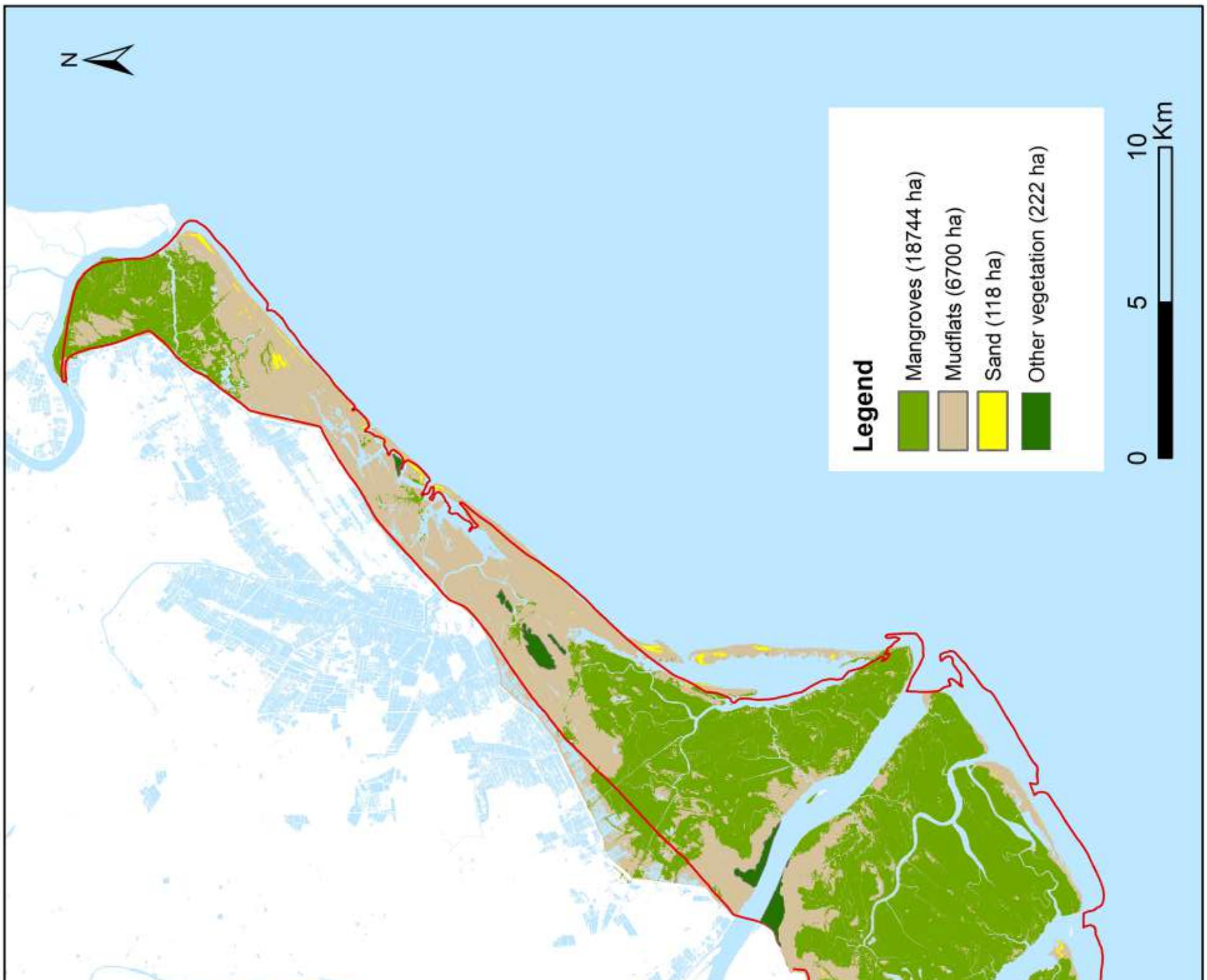


Figure 37: Land Use and Land Cover in 2023

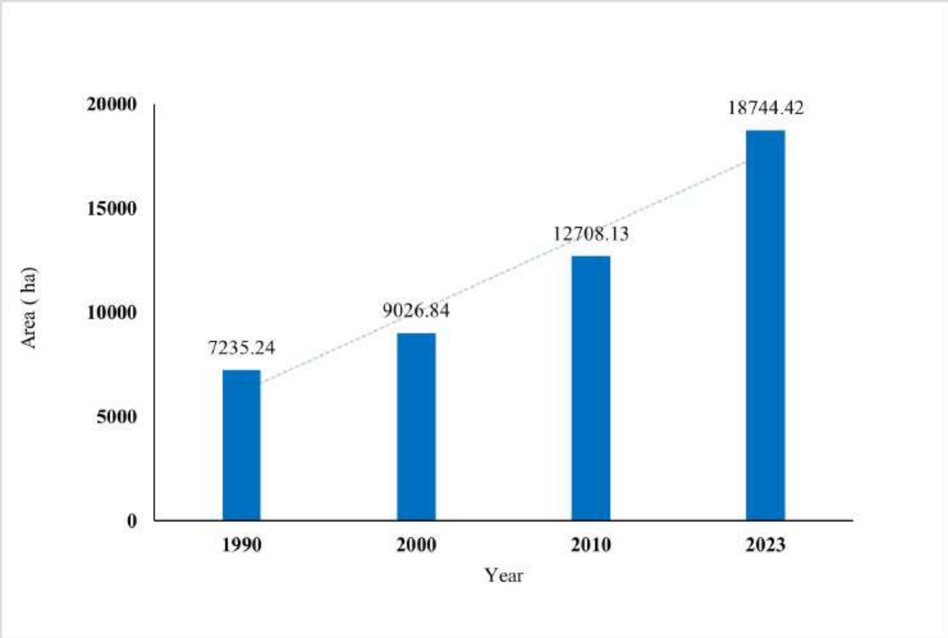


Figure 38: Change in Mangrove Cover between 1990 and 2023

Similar to the Godavari mangrove wetland, substantial mangroves are found outside the reserve forests, indicating the need to conserve them in the same lines of the reserve forests (Table 15).

Table 15: Extent of Mangroves inside and outside the Reserve Forest areas in the Krishna wetland.

Assess-ment Year	The extent of Mangroves inside the Reserve Forests (ha)	Extent of Mangroves outside the Reserve Forests (ha)	Total mangroves (ha)
1990	7,025	210	7,235
2000	8,576	451	9,027
2010	11,834	873	12,708
2023	17,457	1,287	18,744

4.11. Shoreline changes in the Krishna Mangrove Wetland

Between 1990 and 2023, the Krishna coast experienced both erosion and accretion. Erosion was indicated by negative values ranging from -31 to 0 meters per decade. This could be attributed to reduced sediment supply through the river water runoff due to damming upstream, coastal currents, rising sea levels and extreme weather events like cyclones. In contrast, positive values ranging from 0 to 28 meters per decade revealed accretion, likely resulting from sediment deposition, sheltered coast, favourable tidal actions, or changes in river discharge. Notably, the southern part of the Krishna coast showed more signs of erosion, while the eastern and western coastal segments experienced accretion over time (Figs. 39 & 40).

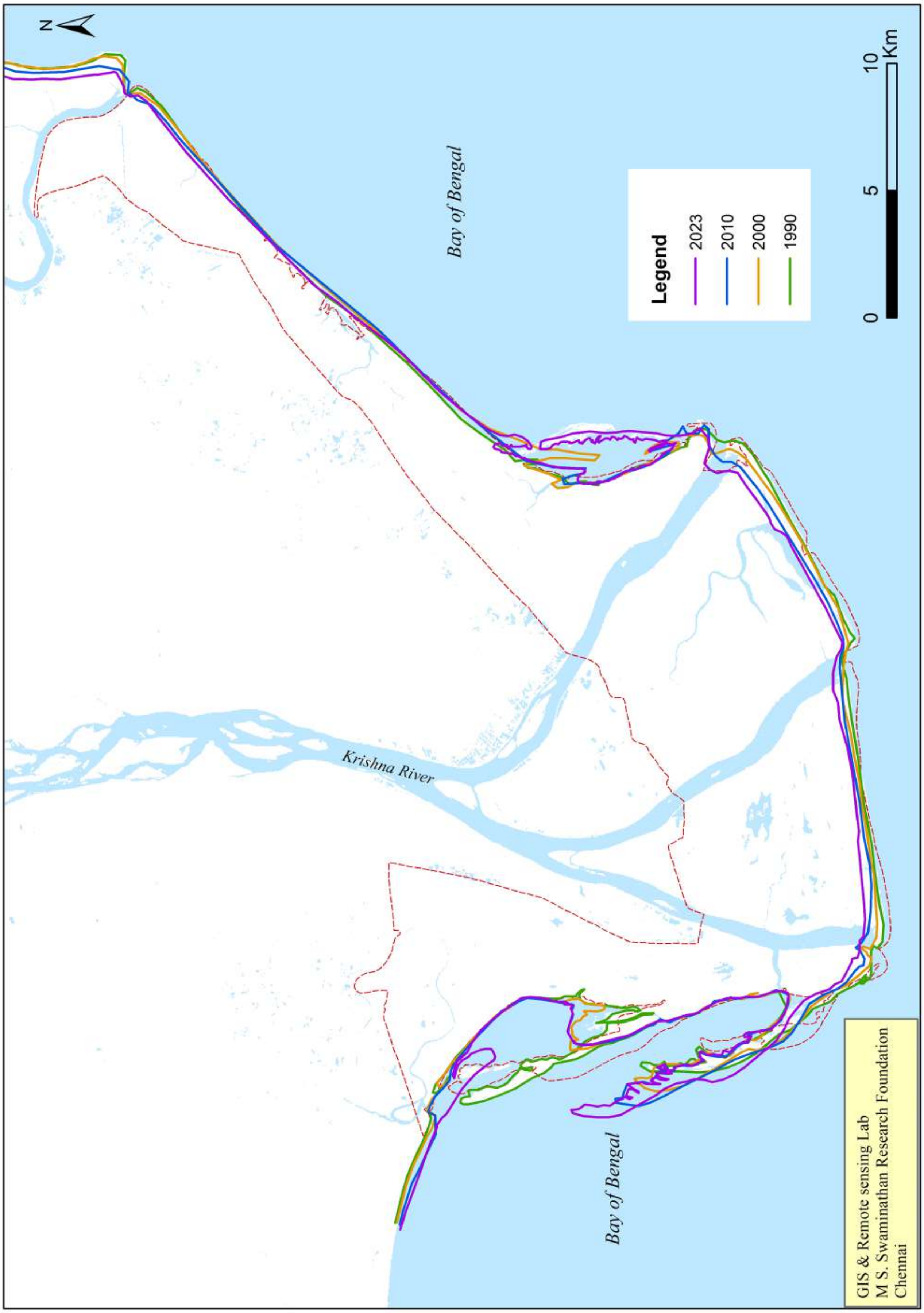


Figure 39: Shoreline of the Krishna coast from 1990 to 2023

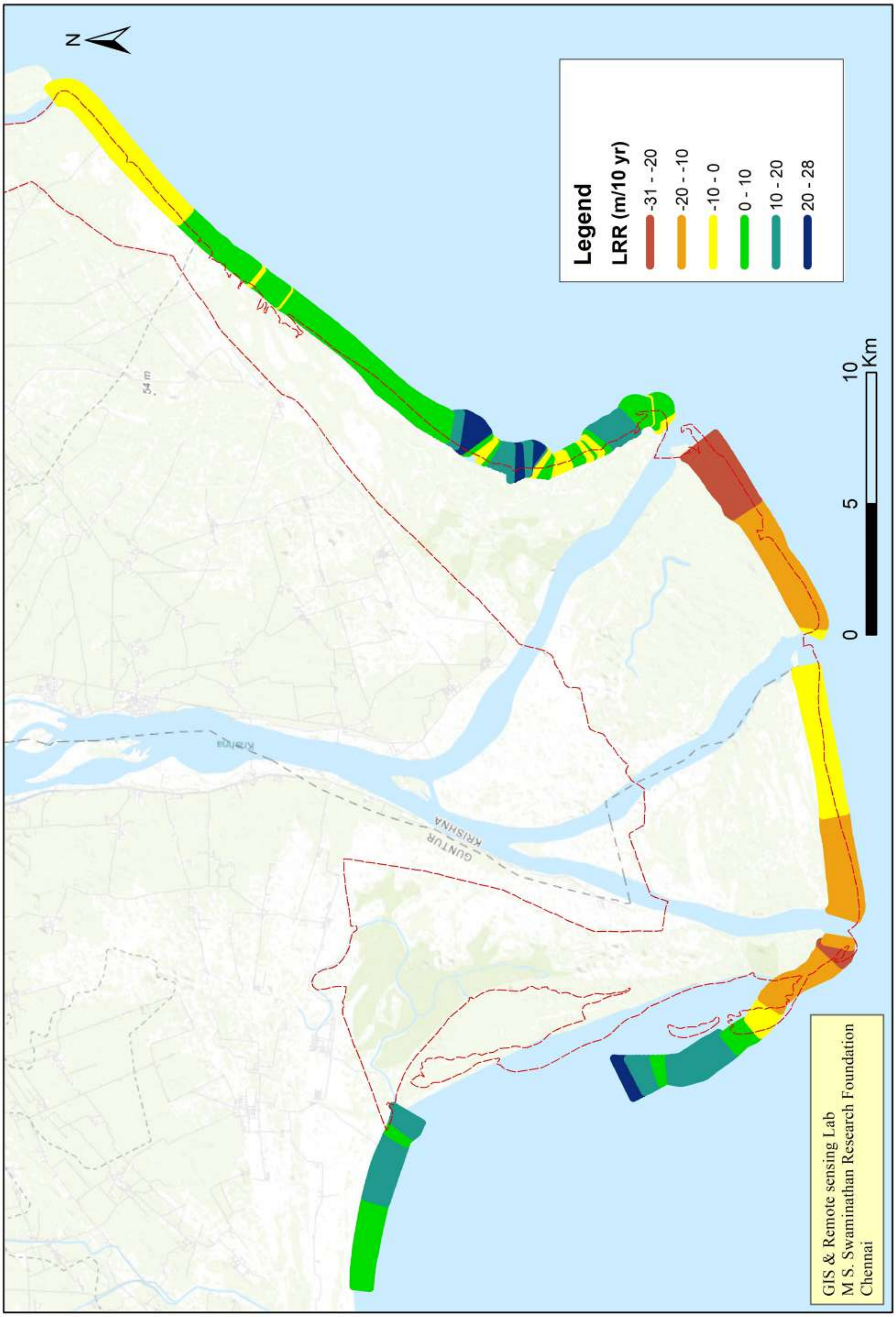


Figure 40: Shoreline changes in the Krishna coast between 1990 and 2023

4.12. Decadal changes in the mangrove cover in the Krishna wetland between 1990 and 2023

Similar to the Godavari mangrove wetland, decadal changes in mangrove cover in the Krishna region were assessed using supervised classification of Landsat imagery. This assessment helps to determine the status and decadal trends in the Krishna mangrove wetland.

4.12.1. Changes between 1990 and 2000

The changes between 1990 and 2000 in the Krishna mangrove wetland showed an increase in mangrove cover, mainly due to the restoration of mangroves in degraded areas, coupled with natural regeneration. The increase in mangrove cover was about 2,222.99 hectares. In comparison, the loss was merely 431.39 hectares, resulting in a net gain of 1,783.6 hectares (Fig. 41). Newly formed mangrove areas expanded into the degraded areas, and mudflats received tidal water flow. The sediment deposition along the lagoon and in sheltered places, where wave action is less, supports the natural formation of mangroves. Although the overall extent of mangroves increased, some areas were lost due to changes in land use for aquaculture and shoreline erosion.

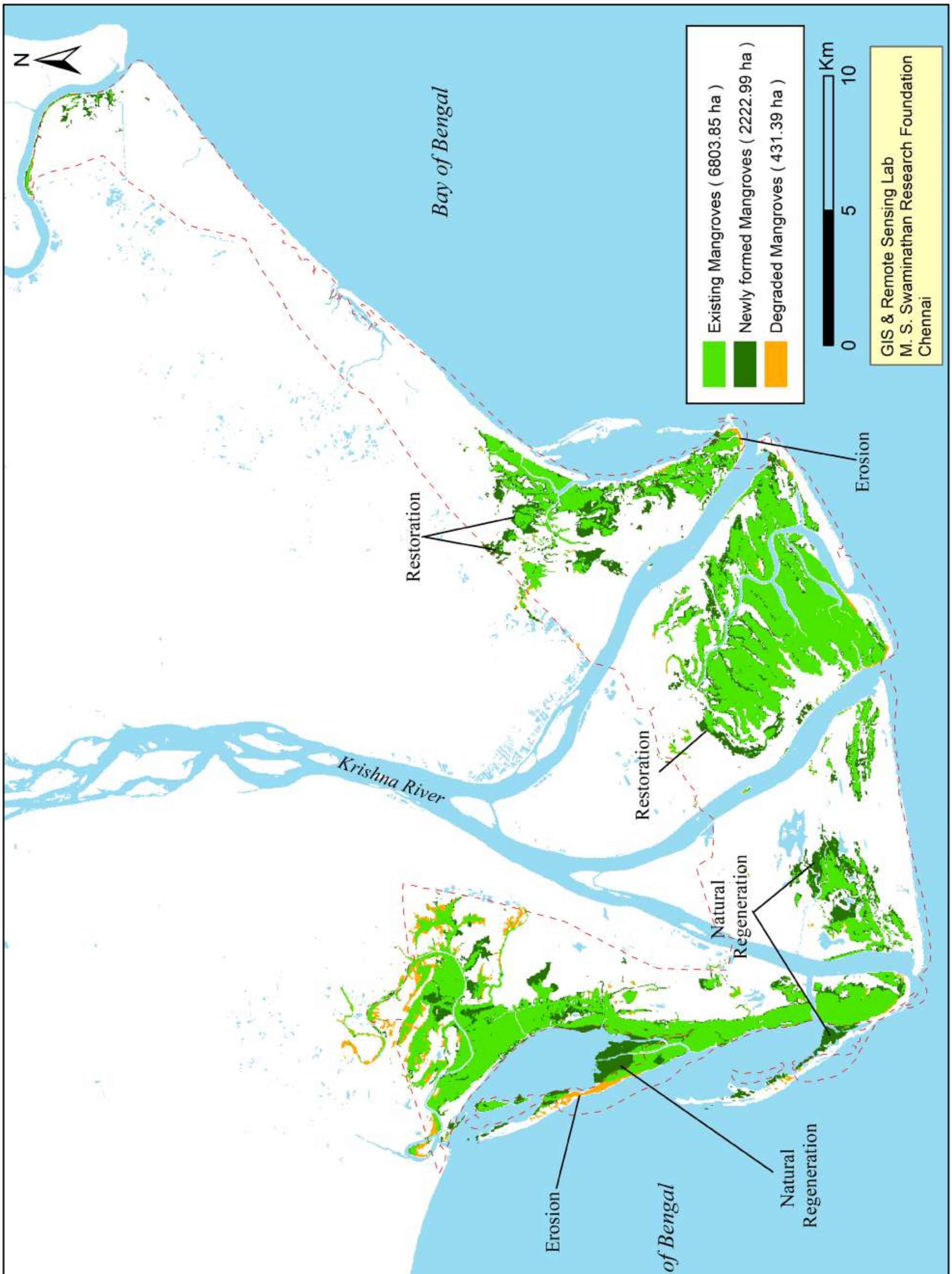


Figure 41: Changes in the Mangrove Cover between 1990 and 2000

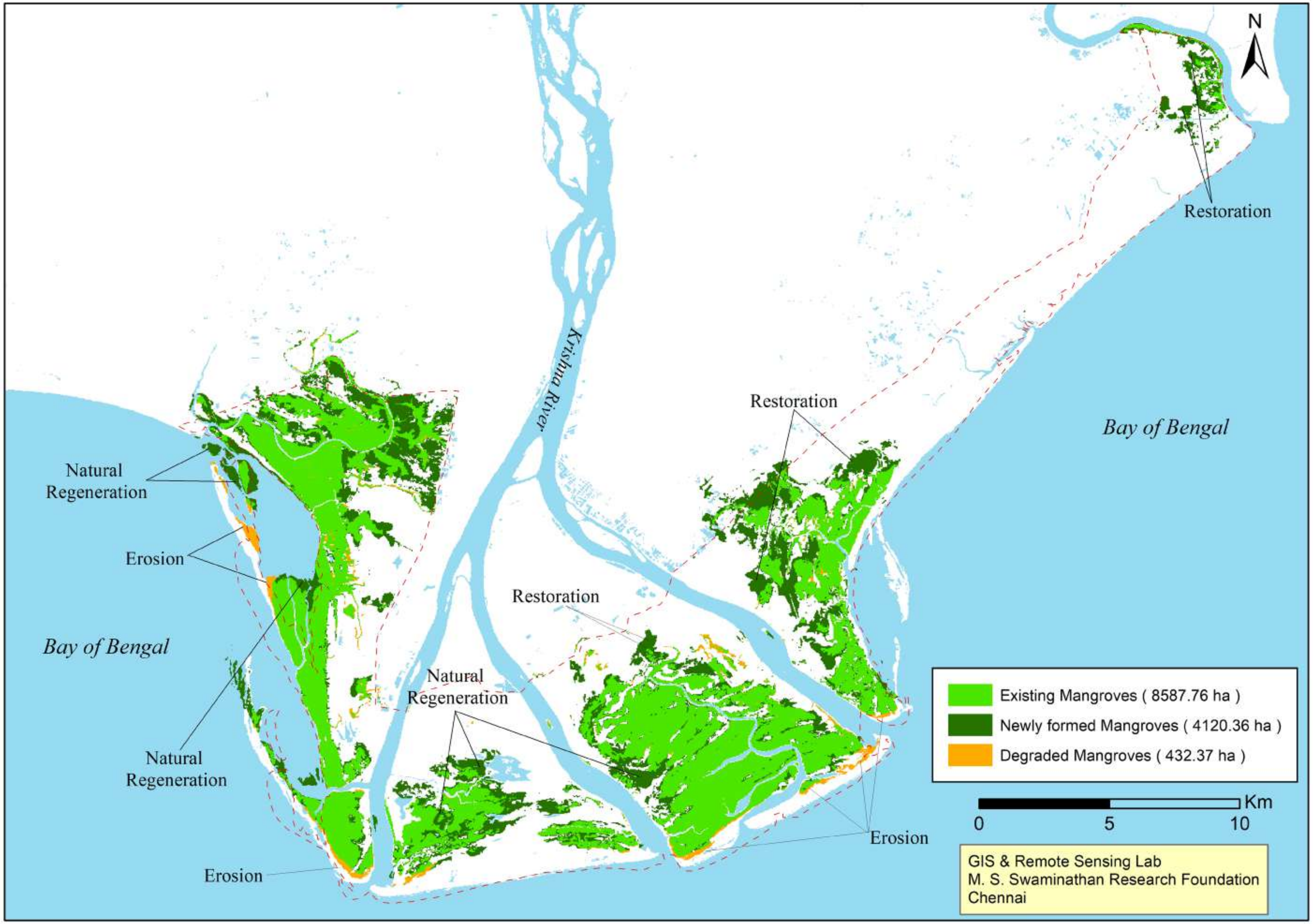


Figure 42: Changes in the Mangrove Cover between 2000 and 2010

4.12.2. Changes between 2000 and 2010

The mangrove cover change between 2000 and 2010 showed a significant increase in mangrove cover, with newly formed mangroves covering 4,120.36 hectares, while losses remained minimal at 432.37 hectares, resulting in a net gain of 3,687.99 hectares (Fig. 42). This growth was primarily driven by natural regeneration in interior regions and restoration efforts in the degraded areas of the Krishna Wildlife Sanctuary. Mangrove loss during this period was confined mainly to the shoreline, where erosion impacted seaward mangroves.

4.12.3. Changes between 2010 and 2023

The significant increase in mangrove cover between 2010 and 2023 was driven by the expansion of newly formed mangroves (6,762.54 ha), primarily due to enhanced restoration efforts across most parts of the Krishna Wildlife Sanctuary and natural regeneration in selected areas. The loss of mangroves in 301.82 hectares was caused by coastal erosion affecting seaward mangroves. Overall, the net increase in mangrove cover during this period was 6,460.72 hectares (Fig. 43).

Between 1990 and 2023, the region experienced significant mangrove expansion, with gains consistently exceeding losses (Fig. 44). Over these 33 years, the overall net increase in mangrove cover reflects the success of conservation and restoration initiatives. Restoration efforts, natural regeneration, and conservation efforts have enhanced mangrove cover, contributing to their long-term stability and sustainability.

Figure 43: Changes in the Mangrove Cover between 2010 and 2023

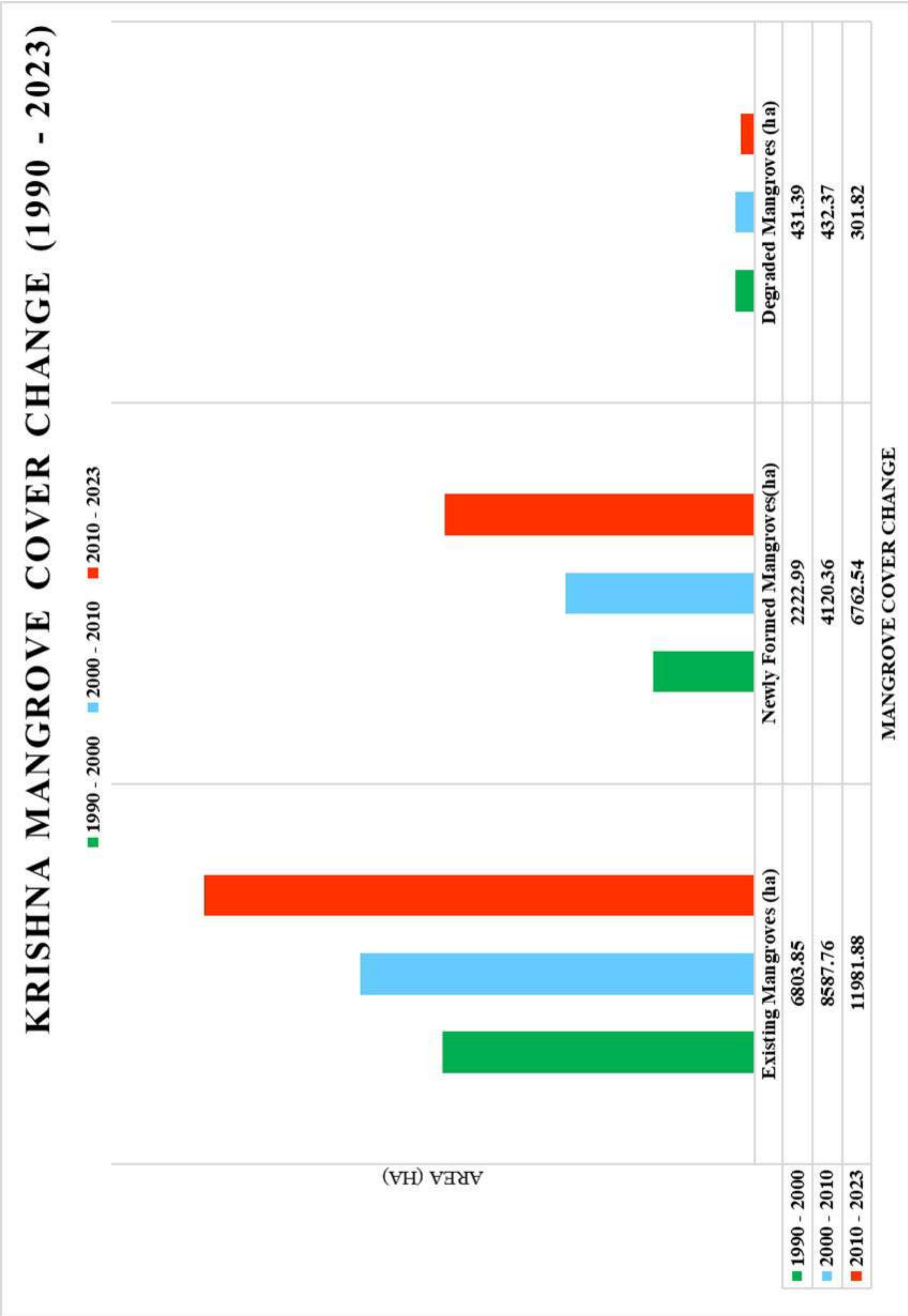


Figure 44: Changes in the Mangrove Cover between 1990 and 2023

4.13. Dependency on the Krishna Mangroves

The fisher-folk residing in 25 coastal villages depend on fishing in the mangrove wetlands (Fig. 45). The Yanadi tribal community living near the mangrove wetlands depends on the collection of crabs for their livelihood. They live inside the mangroves for nearly six months. Cattle grazing in mangrove areas inhibits mangrove growth and the establishment of young seedlings. The cattle eat up young leaves of *Avicennia marina*, which aborts or limits the growth of mangrove saplings. A large number of cows graze near the Palakaitippa village. Mangroves are also a source of firewood, fishing poles, timber for constructing houses, and fencing for their houses. Many villagers still rely on mangroves for fencing, and this dependency is particularly pronounced in the Krishna delta compared to the Godavari delta.

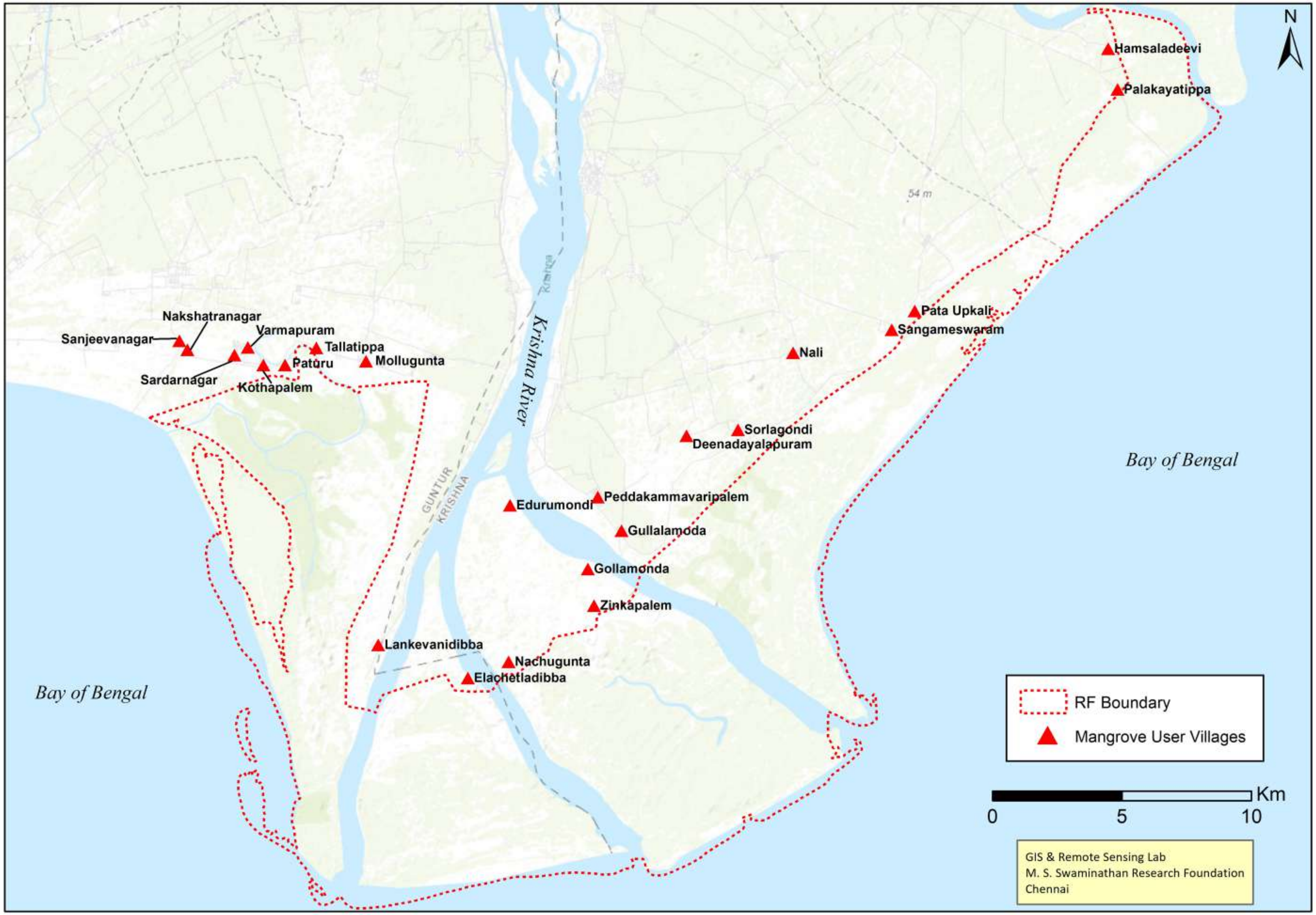


Figure 45: Mangrove Dependent Villages in the Krishna Wetland

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