CLIMATE RISK ASSESSMENT OF POINT CALIMERE WILDLIFE AND BIRD SANCTUARY, TAMIL NADU

INTERNATIONAL CLIMATE INITIATIVE

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ABBREVIATIONS AND ACRONYMS

ACF	ASSISTANT CONSERVATOR FOREST
ADB	ASIAN DEVELOPMENT BANK
CAM	CLIMATE CHANGE ADAPTATION AND MITIGATION
CDA	CHILIKA DEVELOPMENT AUTHORITY
CIFRI	CENTRAL INLAND FISHERIES RESEARCH INSTITUTE
CM5A	COUPLE MODEL VERSION 5
CMIP5	COUPLED MODEL INTERCOMPARISON PROJECT VERSION 5
COP	CONFERENCE OF THE PARTIES
CRA	CLIMATE RISK ASSESSMENT
CRZ-I	COASTAL REGULATION ZONE I
CWC	CENTRAL WATER COMMISSION
DEST	DEPARTMENT OF ENVIRONMENT AND TECHNOLOGY
DFO	DIVISIONAL FOREST OFFICE/DISTRICT FOREST OFFICER
DRM	DISASTER RISK ASSESSMENT
EDCs	ECO DEVELOPMENT COMMITTEES
ESZs	ECO-SENSITIVE ZONES
FAO	FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
FH & FLCS	FISH HARBOURS AND FISH LANDING CENTRES
FPOS	FARMER PRODUCER ORGANISATIONS
GDD	GROWING DEGREE DAYS
GEnS	GLOBAL ENVIRONMENTAL STRATIFICATION
GIS	GEOGRAPHIC INFORMATION SYSTEM
GIZ	DEUTSCHE GESELLSCHAFT FÜR INTERNATIONALE ZUSAMMENARBEIT GMBH
GVS	GREAT VEDARANYAM SWAMP
HIMCOSTE	H.P. COUNCIL FOR SCIENCE, TECHNOLOGY & ENVIRONMENT
HP	HIMACHAL PRADESH
HPSWA	HIMACHAL PRADESH STATE WETLAND AUTHORITY
ICEM	INTERNATIONAL CENTRE FOR ENVIRONMENTAL MANAGEMENT
ICMAM	INTEGRATED COASTAL AND MARINE AREA MANAGEMENT
IMD	INDIA METEOROLOGICAL DEPARTMENT
INRM	INFLUENTIAL NETWORK RELATION MAP
IPCC	INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE
IPSL-CM5A	INSTITUT PIERRE SIMON LAPLACE – CLIMATE MODEL 5A
IUCN	INTERNATIONAL UNION FOR CONSERVATION OF NATURE

JFMC	JOINT FOREST MANAGEMENT COMMITTEES
KITS	KARUNYA INSTITUTE OF TECHNOLOGY AND SCIENCES
LULC	LAND USE AND LAND COVER
MOEF	MINISTRY OF ENVIRONMENT AND FORESTS
MOEFCC	MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE
MPY	MATSYA POKHARI YOJANA
MSSRF	M.S. SWAMINATHAN RESEARCH FOUNDATION
MUY	MATSYJIBI UNAYANA YOJANA
MW	MEGAWATT
NAPCC	NATIONAL ACTION PLAN ON CLIMATE CHANGE
NEWS	NATURE ENVIRONMENT AND WILDLIFE SOCIETY
NPCA	NATIONAL PLAN FOR CONSERVATION OF AQUATIC ECOSYSTEMS
NREGA	NATIONAL RURAL EMPLOYMENT GUARANTEE ACT 2005
NTFPS	NON-TIMBER FOREST PRODUCTS
PMSBY	PRIME MINISTER SURAKSHA BIMA YOJANA
PRECIS	PROVIDING REGIONAL CLIMATES FOR IMPACTS STUDIES
RAINFOREST CRC	COOPERATIVE RESEARCH CENTRE FOR TROPICAL RAINFOREST ECOLOGY AND MANAGEMENT
RCDC	REGIONAL CENTRE FOR DEVELOPMENT COOPERATION
RCP	REPRESENTATIVE CONCENTRATION PATHWAY
RF	RESERVE FOREST
RIDF	RURAL INFRASTRUCTURE DEVELOPMENT FUND
RIS	RAMSAR SITES INFORMATION SERVICE
SAPCC	STATE ACTION PLAN ON CLIMATE CHANGE
SEP	SELF-EMPLOYMENT PROGRAMME
SGCCC	STATE-LEVEL GOVERNING COUNCIL ON CLIMATE CHANGE
SLR	SEA LEVEL RISE
THI	TEMPERATURE HUMIDITY INDEX
TN-ICPP	TAMIL NADU-INTEGRATED COASTAL PROTECTION PLAN
UN	UNITED NATIONS
WBCIS	WEATHER-BASED CROP INSURANCE SCHEME
WIAMS	WETLAND INVENTORY, ASSESSMENT AND MONITORING SYSTEM
WRTC	WETLAND RESEARCH AND TRAINING CENTRE
ZSI	ZOOLOGICAL SURVEY OF INDIA

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Summary

Wetland systems are highly vulnerable to climate change. As climatic patterns become more extreme, the impacts on wetlands become more pronounced through alterations in temperature, hydrological regimes and increased incidents and severity of extreme events, including floods, droughts and storms. A strong knowledge base of climate change risks is therefore essential so that site managers can prioritise and plan appropriate adaptation and mitigation actions. This report presents a climate change vulnerability assessment and adaptation planning process for the Point Calimere Wildlife and Bird Sanctuary Ramsar site. The aim is to have the results of this technical and consultative process integrated into the overall management plan to enhance site resilience through effective adaptation to climate change.

POINT CALIMERE WILDLIFE AND BIRD SANCTUARY RAMSAR SITE

Point Calimere Wildlife Sanctuary, along with the Great Vedaranyam Swamp and the Thalainayar Reserved Forest, was declared a Ramsar site in 2002. The total area of the Point Calimere Wetland Complex is 38,500 ha. The Point Calimere Wildlife and Bird Sanctuary Ramsar site is a mix of salt swamps, mangroves, backwaters, mudflats, grasslands and Tropical Dry Evergreen Forest. About 257 species of bird have been recorded there, including waterbird species such as the Spoonbill Sandpiper *(Eurynorhynchus pygmaeus)* and Grey Pelican (*Pelecanus philippensis)*[1]. The sanctuary serves as the breeding ground or nursery for many commercially important species of fish, as well as for prawns and crabs. Many fishers and farmers are dependent on the wetland for their livelihood. The spread of *Prosopis* spp, salinisation of groundwater and changes in the inflow of freshwater are all threats to the wetland habitats and species.

METHODOLOGY FOR THE CLIMATE VULNERABILITY ASSESSMENT AT THE POINT CALIMERE WILDLIFE AND BIRD SANCTUARY RAMSAR SITE

The climate vulnerability assessment at the Point Calimere Wildlife and Bird Sanctuary Ramsar site was conducted using the climate change adaptation and mitigation (CAM) method developed by ICEM as a flexible tool and process for climate change adaptation and mitigation planning and implementation tailored specifically for Ramsar sites. It is a robust framework for systematically identifying climate change risks, their impacts and their adaptation responses. The CAM method combines a range of supporting tools based on international best practices. The intention is to have the vulnerability assessment and adaptation planning process integrated into the regular site management planning cycle.

The CAM method has three main phases: (I) impact and vulnerability assessment; (II) adaptation planning and (III) implementation and feedback. The GIZ and ICEM team worked with site managers and local stakeholders to apply the CAM method to establishing the evidence base for robust and well-informed site management. The CAM method considered four factors in assessing the vulnerability of the target system and its components to climate change: exposure, sensitivity, impact and adaptive capacity, based on an understanding of the threats posed by climate change.

BASELINE CONDITIONS AT THE POINT CALIMERE WILDLIFE AND BIRD SANCTUARY RAMSAR SITE

The Point Calimere Ramsar site has three main habitat types that represent the target assets for this assessment.

Muthupet and Thalainayar mangrove areas

The Muthupet mangroves cover an area of nearly 12,000 ha in the western section of the Ramsar site, with a lagoon of 1700 ha. The mangrove species is mainly *Avicennia marina,* and only 1855 ha of healthy mangrove forest remains, with 7178 ha of the forest degraded[2]. The freshwater from the Cauvery River reaching the area is minimal, and the tidal exchange maintaining the mangroves through a network of creeks has been reduced by progressive siltation of the creeks. The area is important as a breeding and nursery ground for fish, crustaceans, shrimps, crabs and molluscs (oysters and clams). Fishers use a traditional fishing system, maintaining the flow through creeks and catching the fish that move in and out with the tide.

[1] https://rsis.ramsar.org/ris/1210
[2] Gupta, G.V.M., Natesan, U., Murthy, M.R., Kumar, V.S., Viswanathan, S., Bhat, M.S., Ray, A.K. and Subramanian, B.R., 2006. Nutrient budgets for Muthupet lagoon, southeastern India. Current Science, pp. 967–972.

The Thalainayar mangroves are located about 24 km north of Vedaranayam, in the estuary of the Addapar River. It has area with extensive mudflats, sparse mangroves and a very diverse halophytic vegetation, covering 1237 ha. Over the past decade, the Forest Department has been replanting the mangroves. Mangroves in this area largley that escaped the effects of the 2018 cyclone because they are still sparse and relatively small trees. The wetland area remains dry through most of the year, and records very high salinity (90 ppt) during the dry season. The area is only flushed during the monsoon, during which large numbers of migratory birds visit.

Point Calimere Wildlife Sanctuary

The Point Calimere Wildlife and Bird Sanctuary contains varied habitats such as Tropical Dry Evergreen forests (TDEF), the adjacent grasslands and sand dunes, which lead to the beaches along the east coast. TDEF covers nearly 15 km^2, with the dominant species being *Manilkara hexandra,* and there is scrubland on the low sand dunes in the western half of the sanctuary. The grassland and the sand dunes are being invaded by *Prosopis juliflora,* which is an aggressive exotic thorny shrub of 3–5 m height or tree growing up to 15 m in height. This is the home of the endangered Blackbuck *(Antilope cervicapra)*, Spotted Deer *(Axis axis)* and feral horses *(Equus caballus).* Olive Ridley sea turtles nest on the beaches. Agriculture, fishing, salt production and provision of tourism facilities are the main livelihood activities of the communities adjacent to the sanctuary.

Mudflats and associated shallow waterbodies

The Great Vedaranyam Swamp includes the Panchanathikulam wetland area and an unsurveyed salt swamp. The mudflats and associated shallow waterbodies are the breeding and nursery grounds for maritime prawns and fish such as Hilsa and are one of the important feeding areas for migratory birds such as flamingos. There is a long history of salt production with salt pans and aquaculture ponds. In the fringe areas, salt marshes and *Prosopis* spp. are found to a large extent which provides shelter to wildlife especially the avifauna. The swamp provides finfish and shellfish that contribute livelihood opportunities to the local fishing community. The coast of Point Calimere Wildlife and Bird Sanctuary is an important fish landing site for prawns and fish between November and February.

CLIMATE CHANGE AT THE POINT CALIMERE WILDLIFE AND BIRD SANCTUARY RAMSAR SITE

Projections of precipitation and temperature for 2050s at Point Calimere Wildlife and Bird Sanctuary Ramsar site were generated with respect to a baseline period of 1960–1990. The modelling used an ensemble mean method based on three selected GCMs (CCSM4, HadGEM2-ES and MIROC-ESM) applied to the RCP 8.5 scenario.

Precipitation

The total precipitation is projected to increase during the SW and NE monsoon seasons and to decrease during summer (March–May). For the SW monsoon (June–September), precipitation is projected to increase by 67.7 mm (25.3%), from 267.6 to 335.3 mm, by the 2050s. A more significant increase of 113.6 mm from 816.1 mm to 929.7 mm (13.9%) is projected for the NE monsoon. The increase of rainfall in the monsoons will be more significant for immediate upstream areas in the catchment. The increases are likely to be concentrated in more intense events, creating a higher risk of hazards. In contrast, the precipitation is projected to decrease by 14.1 mm (10.7%), during summer, from 131.1 mm to 117.0 mm. No remarkable change is projected for winter (January–February).

Temperature

The temperature is projected to increase by 1.8°C to 2.2°C by the 2050s. Both winters (January–February) and summers (March–May) at Point Calimere Wildlife and Bird Sanctuary will be warmer. The average maximum temperature is projected to increase by 1.8°C (from 29.5°C to 31.2°C) during winter and by 2.1°C (from 33.7°C to 35.8°C) during summer. Summer will be an extreme season with limited rainfall and higher temperature, which will place stress on the forests and associated species. The average maximum temperature is projected to significantly increase during both the SW and NE monsoons, with an increase of 2.2°C (from 34.0°C to 36.1°C) and 1.9°C (from 29.7°C to 31.6°C), respectively.

Extreme events

Point Calimere Wildlife and Bird Sanctuary is likely to be impacted by more intense droughts during summer (March–May) due to the increase in temperature and the decrease in rainfall during this period.

Extreme cyclones and storm surges are expected to increase in frequency and intensity in Point Calimere Wildlife and Bird Sanctuary. This area has a ‘very high’ risk of an increased frequency of cyclones and a ‘low-moderate’ risk of storm surges of up to 5 m. The rainfall is expected to be concentrated in more intense events that cause a ‘higher’ risk of flood hazards. Point Calimere Wildlife and Bird Sanctuary has a ‘very high’ risk of sea-level rise.

IMPACT AND VULNERABILITY ASSESSMENTS

The climate of Tamil Nadu is mainly of the tropical semi-arid type. The geographical location of Tamil Nadu makes it one of the most vulnerable maritime states in India, particularly to tropical cyclones and their associated storm surges. It is frequently subjected to extreme weather conditions of flooding (the coastal districts) and severe droughts (chronically in some areas and periodically in others). The assessment of vulnerability focussed on important assets of the Point Calimere Wildlife and Bird Sanctuary Ramsar site such as mangroves, mudflats and associated shallow waterbodies and Tropical dry evergreen forests.

Vulnerability scores for the key habitats of Point Calimere

Threats	Muthupet and Thalinayar Mangroves					Point Calimere Sanctuary					Great Vedaranyam swamp				
	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul
Precipitation															
Increase of rainfall during SW Monsoon (Jun–Sep) and NE Monsoon (Oct-Dec)	H	L	M	H	M	L	M	M	L	M	H	M	H	H	M
Decrease of rainfall during summer (Mar-May)	L	L	L	M	M	L	M	M	L	M	L	M	M	M	M
Temperature															
Increase of temperature during SW Monsoon (Jun–Sep)	L	L	L	M	M	H	M	H	L	H	H	H	H	L	H
Increase of temperature during NE Monsoon (Oct-Dec)	L	H	M	M	M	M	M	M	L	M	H	H	H	L	H
Increase in temperature during summer (Mar to May)	L	H	M	L	M	H	H	H	VL	VH	H	VH	VH	L	VH
Increase of temperature during winter (Jan-Feb)	L	H	M	M	M	L	M	M	L	M	L	L	L	L	M
Extreme events															
Sea level rise	H	H	H	L	H	H	VH	VH	L	VH	H	H	H	L	H
Cyclones	H	H	H	H	M	VH	VH	VH	VL	VH	VH	VH	VH	L	VH
Storm surge	M	H	M	L	M	M	VH	H	VL	VH	M	VH	H	L	H

Note: **Exp** = Exposure, **Sen** = Sensitivity, **Imp** = Impact, **Adc** = Adaptive Capacity, **Vul** = Vulnerability

Scoring code: VH Very High, H High, M Medium, L Low, VL Very Low

Although scores show differences and sometimes there is only ‘medium’ vulnerability to climate change, the synergistic impacts of climate changes throughout the year on all three habitats and their component assets are likely to be ‘highly’ negative. Seasonal differences are likely to be more extreme, with drier and hotter dry seasons and wetter and hotter monsoon seasons, so that positive and negative impacts will tend to counteract and reinforce existing non-climate threat and trends. When synthesising the detailed assessments, the long-term trends and impacts on the habitats and their assets can be appreciated.

Muthupet and Thalainayar mangrove areas

Even though all the rainfall and temperature impacts are projected to have medium impacts, the long-term pressure on the mangroves will likely lead to an increase in the degraded areas with lower recovery and re-colonisation of the trees after damage from storm events and a sea-level rise. *Avicennia* spp. will remain the predominant species. Only a few shrubs of *Rhizophora* spp. are present. These species were introduced in Muthupet from Pichavaram. Although *Sonneratia* spp. used to grow in Muthupet and Thalainayar mangroves, these species are no longer found in these areas. An increase in the extent of degraded areas of mangroves will reduce carbon sequestration in these areas.

Point Calimere Wildlife and Bird Sanctuary

The Point Calimere Wildlife and Bird Sanctuary, which is a habitat for Tropical Dry Evergreen Forests and the endangered Blackbuck will be affected by the increase in temperature and in extreme events such as cyclones, sea-level rise and storm surges. The extent of grassland will be reduced due to increasing salinisation. The biodiversity, especially the flora, will be affected by the increase in soil and water salinity in the sanctuary. The change in the composition of the flora, especially the loss of grasslands and increase in cover of invasive species such as *Prosopis* spp. will reduce the fodder availability for herbivores.

Mudflats and associated shallow waterbodies

The mudflats and shallow waterbodies in the Great Vedaranyam Swamp are among the important feeding areas for migratory birds such as flamingos. Salt pans and aquaculture ponds are some other land-uses. The swamp provides finfish and shellfish, which contribute livelihood opportunities to the local fishing community. In the fringe areas, salt marshes and *Prosopis* predominate. *Prosopis* provides shelter for the wildlife, especially the avifauna, but is an aggressive invasive species that inhibits the spread of native species.

ADAPTATION PLANS

A range of adaptation measures is presented for dealing with these issues, some of which are already included in the current management plans, such as continued mangrove replanting with a variety of species, including the dominant *Avicennia marina*, gap filling with *Manilkara hexandra* in the TDEF, removal of invasive species such as *Prosopis* in areas that may be replanted with mangroves or TDEF species and desilting of the creeks to ensure tidal exchange.

The storage of freshwater from the monsoon rainfall to replace the freshwater flows from the Cauvery River, which now scarcely reach this part of the delta, will make an important contribution to reducing the problems of increasing salinity. Beach and sand dune protection will be important in limiting the impacts of sea-level rise and storm surges on the sanctuary area and in safeguarding suitable nesting sites for turtles. Earthen embankments may be constructed along the eastern side of the sanctuary to reduce the risks of saline intrusion from the sea-level rise and storm surges. These may be planted with suitable trees as a shelter belt. The control and management of highly saline discharges from the salt pans and polluting runoff from the surrounding agricultural fields will be necessary for maintaining productive water conditions for fisheries and feeding waterfowl, especially the flamingos.

STAKEHOLDER ENGAGEMENT IN SITE MANAGEMENT AND MONITORING

The implementation of those measures will need the coordination and cooperation of the different stakeholders involved with the Point Calimere Wildlife and Bird Sanctuary. The management of the site is complex, with different land ownership and management responsibilities divided between the Forest Department, Fisheries Department, Revenue and Tourism Departments and coupled with the livelihood interests of the salt pan, farming and fishing communities. A climate change adaptation coordination platform under the State Wetland Authority is recommended for securing agreement on the measures that should be implemented over the next decade to protect the site against climate change. This is in the interest of all the stakeholders. Adaptation measures need to be designed and planned in detail with ongoing adjustments on the basis of appropriate research, surveying and monitoring of effectiveness.

1 INTRODUCTION

1.1 Background

Wetlands are highly vulnerable to climate change. As climatic patterns become more extreme, leading to alterations in temperature, rainfall and hydrological regimes, they will reshape wetland ecosystems. A strong knowledge base of climate change risks is essential for Ramsar site managers to prioritise and plan appropriate adaptation and mitigation actions.

ICEM has been commissioned by GIZ India to conduct climate risk assessments and adaptation planning for four Indian Ramsar sites that are the focus of the technical cooperation project *Wetlands Management for Biodiversity and Climate Protection,* implemented by the Ministry of Environment, Forest and Climate Change (MoEFCC), in partnership with GIZ. The four Ramsar sites are **Renuka wetland, Pong Dam lake, Bhitarkanika Mangroves and Point Calimere Wildlife and Bird Sanctuary.** These four sites are upland lakes and reservoirs in Himachal Pradesh and coastal mangrove areas in Odisha and Tamil Nadu and represent two very different ecological and climate conditions.

The current management plans for the sites do not address the impacts of climate change – although many of the good measures identified within them for ecosystem management are also important and appropriate adaptation responses to climate change. Full understanding of the projected risks is essential if site managers are to prioritise and plan appropriate adaptation actions. This assignment to work with site managers and local stakeholders to conduct climate change vulnerability assessment and adaptation planning aims to build a comprehensive adaptation strategy into the management plans and budgets of the four wetland sites. The assessments demonstrate a methodology that can be replicated in other wetland areas across India.

This final report on the climate risk assessment of the **Point Calimere Wildlife and Bird Sanctuary Ramsar site** is one of four covering the four sites. The first chapter is similar in all these reports. The subsequent chapters of this report are specific to Point Calimere:

- **Chapter 1** presents the project background and overall methodology used for climate risk assessments at the four Ramsar sites.
- **Chapter 2** describes the baseline conditions at Point Calimere
- **Chapter 3** provides the climate change profile of the site.
- **Chapter 4** synthesizes and presents results from vulnerability assessments of the target assets (the detailed VA matrices are annexed).
- **Chapter 5** develops the adaptation measures for the site on the basis of the annexed adaptation matrices of the target assets.
- **Chapter 6** provides recommendations for the management of the site and for stakeholder engagement.

1.2 Project aims and objectives

The project aims to support the integration of ecosystem services and climate change risks into management plans of the four Ramsar sites, contributing to the core outputs of the project, Wetlands Management for Biodiversity and Climate Protection.

The specific objectives of the assignment are:

- Identifying and prioritising climate change-related risks at Ramsar sites, including Renuka wetland, Pong Dam lake, Bhitarkanika mangroves and Point Calimere Wildlife and Bird Sanctuary.
- Proposing measures that help reduce the vulnerability of wetlands to changing climate by mitigating the adverse change, minimising exposure, reducing sensitivity and adapting to the changes.

- Proposing interventions for integrating wetland conservation and wise use within the climate change mitigation and adaptation planned for the region under the umbrella of SAPCC (State Action Plan on Climate Change).
- Identifying measures for enhancing awareness and developing capacities at the sites, as well as at the institutional level, to respond to climate change through workshops and training programmes.
- Building the capacity of stakeholders and decision makers in understanding the climate risks and adaptation options.

1.3 Overview of the other three Ramsar sites

1.3.1 Pong Dam Reservoir

The reservoir, located at longitude 76°E and latitude 32°N, drains a catchment area of 12,561 km^2, with 780 km^2 under permanent snow cover (Figure 1). The active storage capacity of the reservoir is 7,290 Mm^3. The stored water is used primarily for meeting irrigation demands downstream. Nearly 7913 Mm^3 of water is released annually to irrigate 1.6 Mha of land. Hydropower generation is achieved by releasing the water through turbines before it is diverted to the agricultural fields. The major crops cultivated in the catchment are rice, wheat, maize and cotton. The monsoon rainfall, between June and September, is a major source of water inflow into the reservoir, apart from snow and glacier melt. The snow and glacier melt runoff in the Beas catchment were studied for the years from 1990 to 2004 by Kumar et al. (2007). The contribution of this runoff is about 35% of the annual flow at Pandoh Dam (upstream of Pong Dam).

The Summer Bird Census in 2015 revealed that the Pong Dam wetland is home to about 423 species of bird, 18 species of snake, 90 species of butterfly, 24 mammal species (Malik & Rai, 2019). According to the latest survey of 2020 (reported by wildlife officials), the number of bird species has gone up marginally compared with 2018.

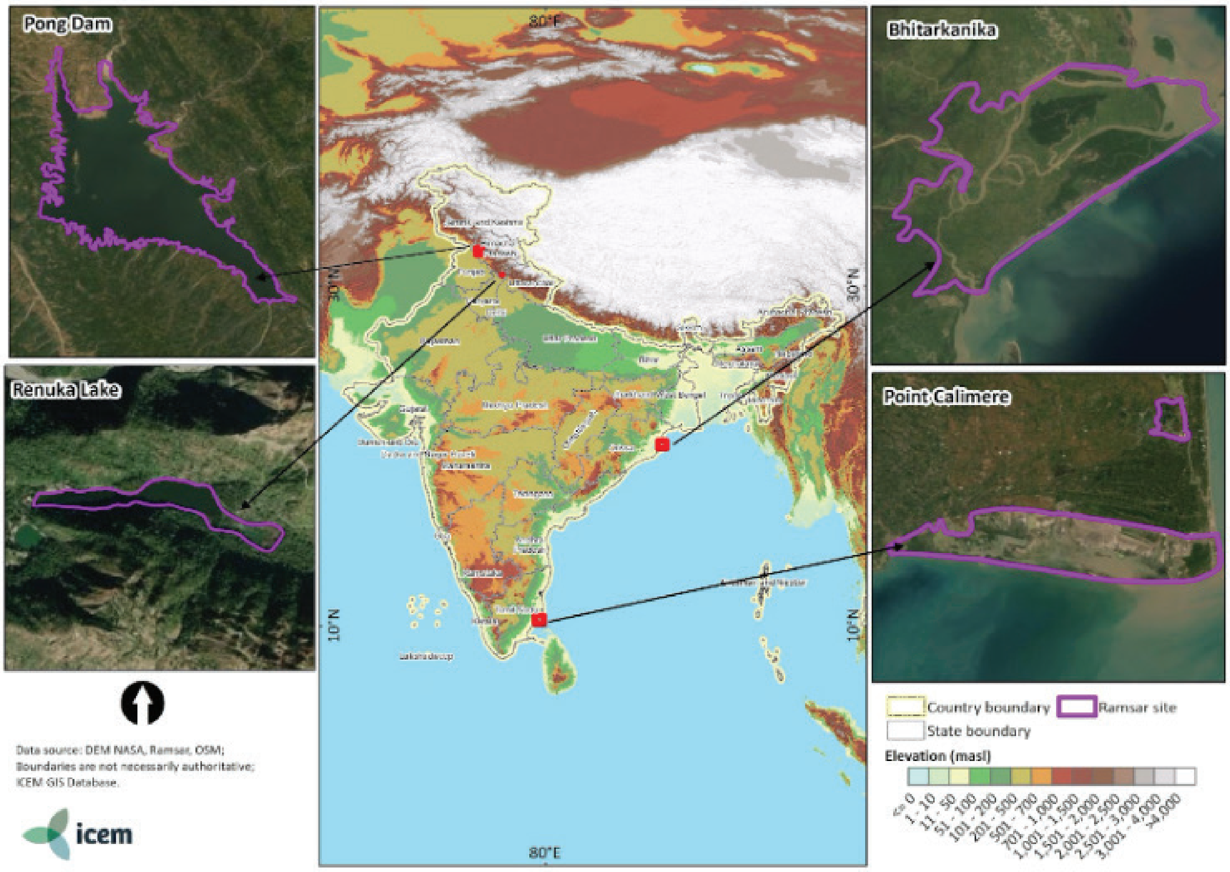

Figure 1 Locations of the four Ramsar sites targeted for vulnerability assessment and adaptation planning

1.3.2 Renuka Wetland

The Renuka wetland (30˚36'N, 77˚27'E) is located at an altitude of 645 m, in Sirmaur district, of Himachal Pradesh (Figure 1). The wetland comprises a large oblong-shaped lake with a small outlet to an adjoining pond, Parashuram Tal, which ultimately drains into the River Giri through a small channel. Lying in a narrow valley between two parallel steep hills, the lake is about five times as long as its breadth, having an area of approximately 30 ha. Its 500 ha catchment area includes about 250 ha of mostly sub-tropical deciduous forest of broad leaved species, bamboo, palm and other wild plants.

The Renuka Wetland Management Action Plan (2013–2022) noted that 103 bird species belonging to 38 families have been identified, with 66 species of resident birds. Renuka is also home to freshwater turtles and feeding them is one of the tourist attractions.

The wetland receives water primarily from springs and southwest monsoon through seasonal streams that also bring large quantities of silt and debris from poorly vegetated areas of the catchment. A perennial underground seepage water supply possibly from the upper Giri River has also been reported.

1.3.3 Bhitarkanika mangroves

The Bhitarkanika mangroves, located in the state of Odisha, India, covers about 65,000 ha on the east coast of India (20˚39'N, 86˚54'E) (Figure 1). It was designated a Ramsar site in 2002. This wildlife sanctuary is one of the finest remaining patches of mangrove forest in the region. The site is visited annually by about 500,000 Olive Ridley sea turtles, making it the world's largest mass nesting beach. It is a habitat for bird nesting and breeding, with 280 species of bird. The site contains one of the largest heronries in Asia. The Bhitarkanika mangroves have the highest density of Saltwater Crocodile in the country, supporting a population of 1700 individuals. It is one of the most diverse mangrove ecosystems in India, with 70 mangrove species. The Bhitarkanika mangrove forests provide vital protection for millions of people from frequent devastating cyclones and tidal surges. This area also supports 250,000 inhabitants in 410 villages who are mainly dependent on agriculture, fishing and aquaculture.

1.4 CAM process – Climate Change Adaptation and Mitigation

The overall process for this assessment followed the steps of the CAM (Climate Change Adaptation and Mitigation) method, which has been developed by ICEM as a flexible methodology to climate change adaptation and mitigation planning and implementation tailored specifically for the assessment of protected areas. It provides a framework for systematically identifying climate change projections, their impacts and the needed adaptation responses. The CAM method combines a range of assessment and planning tools based on international best practices (Annex 1). In the case of the Ramsar sites in India, the aim is to integrate the CAM tools into the regular Ramsar site management planning cycle. The project tested and demonstrated the methodology at the four Ramsar sites, working closely with the site managers and local stakeholders.

The CAM process recognises the fundamental role of natural systems in maintaining and enhancing resilience. It recognises the cyclical and iterative nature of adaptation and mitigation and uses spatial planning as the foundation for adaptation that must be integrated with development planning, in this case, the Ramsar site management plans.

The CAM method has three main phases, with several steps in each, as shown in Figure 2:

(I) Impact and vulnerability assessment

(II) Adaptation planning

(III) Implementation and feedback

1 IMPACT AND VULNERABILITY ASSESSMENT

STEP 1: Determining the scope and target assets

STEP 2: Conducting the baseline assessment

STEP 3: Assessing the impacts of climate change on the assets

STEP 4: Assessing the capacity to avoid or recover from the impacts

STEP 5: Scoring and ranking vulnerability

2 ADAPTATION PLANNING

STEP 6: Identifying adaptation options to address the impacts

STEP 7: Defining the priority measures

STEP 8: Preparing the adaptation plan and supporting measures

3 IMPLEMENTATION AND FEEDBACK

STEP 9: Design and construction of adaptation measures

STEP 10: Monitoring, maintenance and repair

STEP 11: Adaptation phasing, adjustment and retrofitting

STEP 12: Replication and upscaling

Figure 2 *Phases and steps of CAM*

For the vulnerability assessment and adaptation planning, the expert team applied the CAM method to undertake a threat analysis of each site, providing the evidence base for robust and resilient site management. The CAM method considered four important factors in assessing the risk and vulnerability of the target system and its components to climate change: exposure, sensitivity, impact and adaptive capacity, on the basis of an understanding of the threats posed by climate change. Annex 1 describes the CAM tools used for the vulnerability assessment and adaptation planning at the four Ramsar sites.

1.5 Stakeholder involvement and capacity building

Building the capacity of management agencies, wetland user groups and stakeholders is a recognised component of the adaptation strategies needed at each Ramsar site. For this project, the wetland management staff and other stakeholders were closely involved in the vulnerability assessment process and in validating the assessments and exploring the adaptation options. The process also had the benefit of field missions and stakeholder consultations conducted by the project team that were geared towards the important phases of the assessment and identification of adaptation measures, namely:

- Developing the baseline and identifying the target assets for vulnerability assessment
- Carrying out the vulnerability assessment to define the direct and indirect impacts
- Conducting the adaptation planning to identify and prioritise the adaptation options

During the field missions, a stakeholder analysis was developed, building on the initial sections in the baseline descriptions in Chapter 2 of this report. The analysis was used to guide follow-up meetings with stakeholder groups during the virtual consultations. This process is summarised in Table 1.

Table 1 *Capacity development and institutional strengthening*

Activity	Description
Organising capacity building workshops and training programmes in climate risk assessment and adaptation for site managers, stakeholders and local organisations	• Capacity building and increasing awareness of climate change risks and adaptation measures are included at the stakeholder consultation workshops, where the vulnerability assessments and adaptation planning are presented and discussed. • Consultation workshops were conducted during the field missions to the Ramsar sites and during the virtual consultation process.
Preparing climate risk assessment frameworks and guidance documents for wetlands that incorporate the learning from the assessment	**Various documents have been prepared, including:** • A CAM methodology guide for training and application in other Ramsar sites • Climate risk profile and vulnerability assessment for four wetland sites • EbA action plan recommendations for each wetland site, as part of the VA and AP reports

2 BASELINE ASSESSMENT FOR POINT CALIMERE Wildlife AND BIRD SANCTUARY

2.1 Site description

Point Calimere Wildlife and Bird Sanctuary (10°18′N, 79°51′E), along with the Great Vedaranyam Swamp and the Thalainayar Reserved Forest, was declared a Ramsar site in November 2002 (Figure 3)3. The total area of thePoint Calimere Wildlife and Bird Sanctuary wetland complex is 38,500 ha, which encompasses the wetland areas shown in Table 2 and identified in Figure 4.

[3] Declaration No.1210 at the 8th meeting of the Conference of the Parties (COP 8) held at Velancia from 18-26th

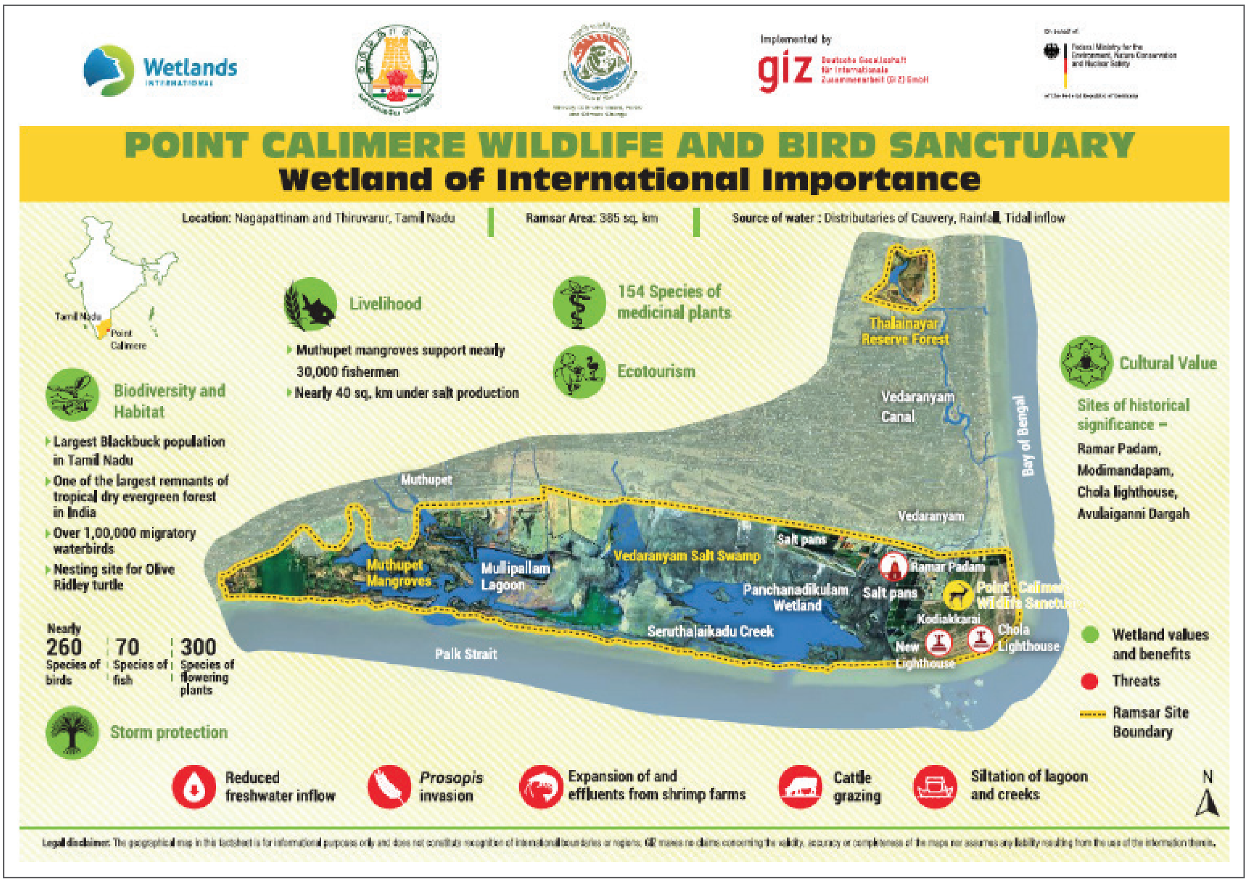

Figure 3 *Point Calimere Wildlife and Bird Sanctuary - Overview poster*
(Source: Indo-German Biodiversity Programme, Biodiversity conservation)

Table 2 *Different wetland areas of the Point Calimere Wildlife and Bird Sanctuary*

Wetland Type	Area (ha)
Point Calimere Wildlife Sanctuary	2250.17
Muthupet mangroves	11,885.91
Panchanathikulam wetlands	8096.96
Un-surveyed salt swamps	15,030.19
Thalainayar Reserve Forests	1236.77
TOTAL	**38,500.00**

The forests of Point Calimere, in Nagapattinam district, of Tamil Nadu, were declared the Kodiyakarai Reserve Forest and the Kodiyakarai Extension Reserve Forest in 1907, which gave the areas some level of protection. In June 1967, the Point Calimere Wildlife Sanctuary was established. The sanctuary has a mix of Tropical Dry Evergreen Forest (TDEF), mudflats, grasslands, backwaters and sand dunes. The Great Vedaranyam Swamp extends 48 km towards Muthupet town and is fringed with mangrove vegetation. There are many salt pans adjoining the sanctuary (Figure 4).

The Tropical Dry Evergreen Forest (TDEF) here are among the best-preserved anywhere of this almost extinct forest type. These forests exist despite a rainfall of only 1250 mm per annum4. These forests once existed all along the Coromandel Coast. Tropical Dry Evergreen Forest (TDEF) covers nearly 15 km^2 of Point Calimere Wildlife and Bird Sanctuary. The forests are mostly of the nature of scrubland that stands on low sand dunes located on the western half of the sanctuary. Manilkara hexandra, locally called Palai, is the most important dominant evergreen tree species of the sanctuary.

[4] India Meteorological Department, 2020. Observed Rainfall Variability and Changes Over Tamil Nadu State. Issue No. ESSO/IMD/HS/Rainfall Variability24 (2020)/48.

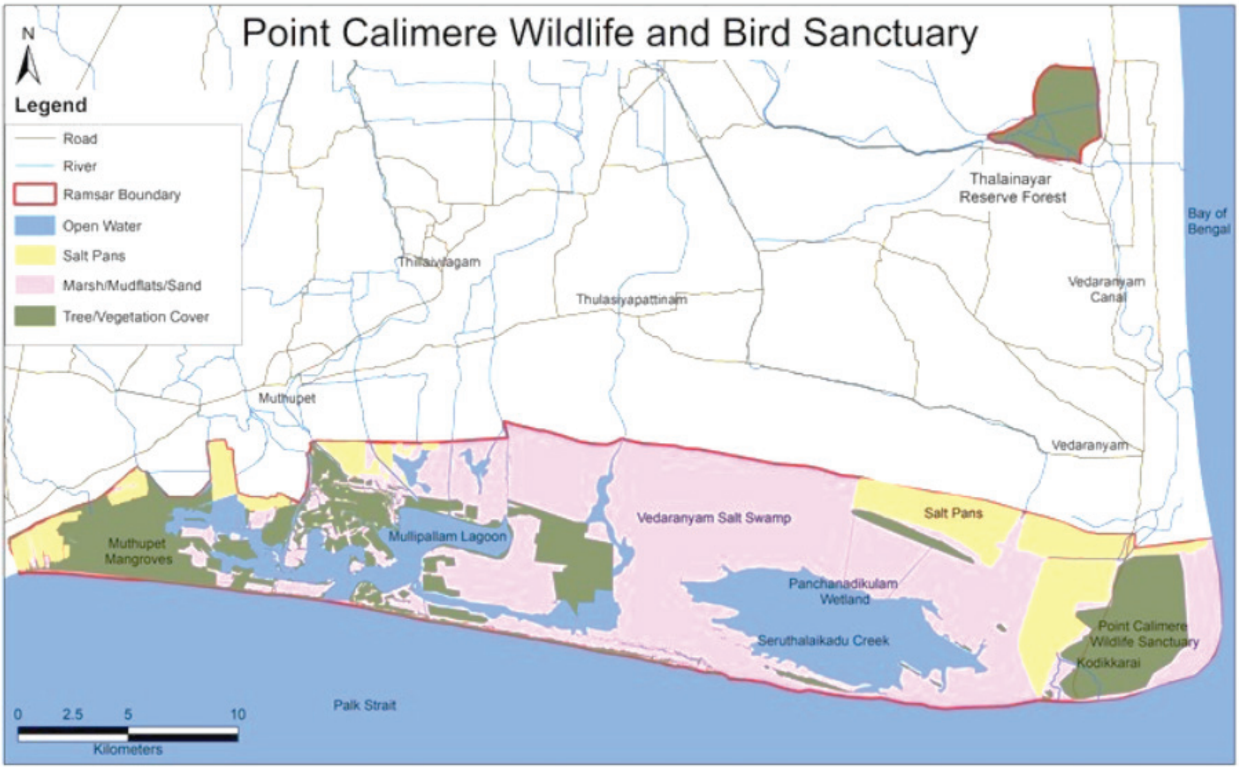

Figure 4 *Wetland areas around Point Calimere Wildlife and Bird Sanctuary*

Lannea coromandelica, which is an introduced species, is the only deciduous species found here. The forest supports about 154 species of medicinal plant such as *Mucuna pruriens, Solanum trilobatum, Tinospora cordifolia, Randia dumatorum* and *Cissus quadrangularis.* The dominant grass in the grassland areas is *Aeluropus lagopoides,* followed by *Sporobolus tremulus* and Cressa cretica. The sand dunes are largely colonised by *Prosopis juliflora* and *Calotropis gigantea.* In total, 317 flowering plants have been identified inside the sanctuary. These include two species of Drosera, an insectivorous plant. It is home to the largest population of the endemic Blackbuck in south India. Other animals of the sanctuary include the Jackal, Spotted Deer, Jungle Cat, feral horses, Black-naped Hare and a variety of reptiles. Agriculture, fisheries and salt production are the main sources of livelihood around the bird sanctuary.

Muthupet Mangroves

Muthupet is situated at the southern end of the Cauvery delta. Paminiyar, Koraiyar, Kilaithathangiyar, Marakkakoraiyar and other distributaries of the river Cauvery flow through Muthupet mangroves. At the tail end, they form a lagoon before joining the Palk Bay. In February 1937, the Government of Tamil Nadu declared the mangrove forest a reserve, divided into the Palanjur, Thamarankottai, Maravakkadu, Vadakadu, Thuraikadu and Muthupet reserve forests. The Muthupet mangrove wetland is at the southernmost end of the Cauvery delta and occupies an area of approximately 12,000 ha, including a 1,700 ha lagoon[5]. However, healthy mangroves cover only about 1855 ha – nearly 7,178 ha is degraded[6]. Muthupet is dominated by a single species, *Avicennia marina*. Other mangrove species – *Acanthus ilicifolius, Aegiceras corniculatum, Rhizophora apiculata, Excoecaria agallocha* and *Lumnitzera racemosa* – have been reported from the wetland, but their populations are very limited. Lack of sufficient freshwater flow is the main reason for the presence of only a few mangrove species.

Seaweeds such as *Chaetomorpha sp*., *Enteromorpha sp*., *Gracilaria sp.* and *Hypnea* are found in the Muthupet wetland, which also supports finfish, shrimps, molluscs, crabs and benthic invertebrates. The finfish constitute the bulk of the fishery in the Muthupet mangroves. The Flathead Grey Mullet *(Mugil cephalus),* Lebranche Mullet *(Liza sp.),* Milkfish *(Chanos sp.),* Rabbit Fish *(Siganus sp.)* and Green Chromide Cichlid *(Etroplus sp.)* are common.

[5] Arunprasath, A. and Gomathinayagam, M., 2014. Distribution and composition of tru mangroves species in three major coastal regions of Tamilnadu, India. Int J Adv Res, 2, pp. 241–247.
[6] Gupta, G.V.M., Natesan, U., Murthy, M.R., Kumar, V.S., Viswanathan, S., Bhat, M.S., Ray, A.K. and Subramanian, B.R., 2006. Nutrient budgets for Muthupet lagoon, southeastern India. Current Science, pp. 967–972.

The shrimp fishery is dominated by *Penaeus indicus, Penaeus monodon, Metapenaeus dobsoni, Metapenaeus monoceros* and *Macrobrachium sp.* The commercially important Mud Crab *(Scylla serrata),* Sand Crab *(Portunus pelagicus)*, oysters *(Crassostrea madrasensis)* and clams *(Meretrix meretrix)* are recorded in this area. Birds such as herons, egrets, kingfishers, plovers and sandpipers are also common.

Thalainayar Reserve Forest

The Thalainayar Reserve Forest, which is not contiguous with Point Calimere Forests and the Great Vedaranyam Swamp, is located nearly 24 km north of Vedaranyam. It is situated near the estuary of the River Adappar, which flows into the Bay of Bengal near Kallimedu. The region has characteristic salt-marsh vegetation (Buceros, ENVIS Newsletter, 1999). This site has a large extent of mudflats with sparse mangrove and halophyte vegetation. It was declared a reserve forest in 1931. The backwater–lagoon-like habitat receives freshwater from distributaries of the Cauvery during the monsoon and opens into the Bay of Bengal through the Adappar River, which is connected to the Vedaranyam canal. *Avicennia marina* is the dominant mangrove species. In all, 3 mangrove species, 18 mangrove-associated species, including halophytes and macroalgae, 5 species of crab, 36 avian species and 15 molluscs have been reported from this habitat.

The Reserve Forest is bounded by the Adappar River on its south and by the Vedaranyam canal on its east. The Puduar river runs through the middle of the reserve from east to west, connecting the Vedaranyam canal to the Malaialam lagoon, located inside the reserve. Except for the lagoon, the wetland remains dry for most of the year. However, during the northeast monsoon, from October to January, the area is flooded and abounds with water birds. The prominent water birds visiting this wetland include species such as the Painted Stork, Greater Flamingo, Grey Heron, Openbill Stork, Large Egret, Pintail and Common Teal. Compared with Point Calimere Wildlife and Bird Sanctuary, the variety of water birds is lower due to the smaller wetland area and a relatively higher level of water salinity, which reaches up to 90 ppt during summer.

Mudflats and associated shallow waterbodies

The mudflats and shallow waterbodies in the Great Vedaranyam Swamp (GVS), including the Panchanathikulam wetland and un-surveyed salt swamp, have a long history of salt production. Several domestic and industrial salt works operate in the GVS. There was a great change in land use after the 2004 Indian Ocean tsunami as the salinity levels of the groundwater increased. Farming activities stopped because of seawater intrusion. The impact of salt works also alters the ecosystem, affecting the flora and fauna of the GVS, besides having possible repercussions on the coastal fisheries. The flow of freshwater from the River Cauvery has reduced significantly, affecting the biodiversity in and around the GVS. The mudflats and associated shallow waterbodies serve as the spawning and nursing ground for commercially important maritime prawns and fishes, such as the Indian White Prawn *(Penaeus indicus),* the Giant Tiger Prawn *(P. monodon),* the Hilsa Shad *(Hilsa ilisha)* and milkfishes *(Chanos chanos).* The swamp also has large populations of mullet and exotic tilapia *(Oreochromis mossambicus).* The Mud Crab *(Scylla serrata)* is also a commercially important species. From November to February, the coast of Point Calimere is an important fish landing site for fishes and prawns.

2.2 Identification of target assets

On the basis of the findings of the field missions, three key habitats were selected for further assessments, together with several other key assets of the Point Calimere ecosystem (Table 3). The scoring of each asset is shown in Table 4, which enabled the selection of the critical assets of the site.

Table 3: Selected target assets of Point Calimere

Asset Name		Description
Key Habitat	Mangroves	• Mangroves in Muthupet are being degraded due to climatic conditions (Gaja cyclone in 2018) and the increase in temperature. The siltation in Muthupet lagoon is increasing. Reduction in mangrove extent due to Gaja cyclone – about 3 km^2 mangroves lost in Muthupet. • Thalainayar is included in Muthupet mangroves as the climate change issues are very similar. • Muthupet lagoon is considered as part of the Muthupet mangroves
		Main assets: • Mangrove species - *Avicennia,* invasive species, crustaceans and fish, fisheries, carbon sequestration
Key Habitat	Point Calimere Sanctuary	• The Tropical Dry Evergreen Forest (TDEF) covers nearly 15 km^2 of Point Calimere Wildlife and Bird Sanctuary, and it is one of the best-preserved forests of its kind. The forests are mostly of the nature of scrubland that stands on low sand dunes located on the western half of the sanctuary
		Main assets: • Tropical Dry Evergreen Forest - *Manilkara hexandra,* invasive species - *Prosopis juliflora* • Mammals – Blackbuck; Olive Ridley sea turtles nesting
Key Habitat	Mudflats and associated shallow waterbodies	• An important feeding ground for birds; highly productive; fishing ground for small fishers • Protects from flooding; coastal and rainwater stored in the lagoon and swamp; siltation in the swamp; shallow; infestation with barnacles. • Siruthalaikadu lagoon is part of the Great Vedaranyam Swamp.
		Main assets: • Lagoon, saltmarsh, salt pans and salt production, plankton and invertebrates, flamingos, crustaceans and fish, fisheries

Table 4 Scoring for critical asset selection

Criterion	Question	Mangroves	Tropical Dry Evergreen Forests	Mudflats And Associated Shallow Waterbodies
Representativeness	To what extent is the habitat, species or ecosystem service representative of the site?	4[7]	4[8]	4[9]
Ecological significance	To what extent is the habitat, species or ecosystem service significant for ecological processes?	3[10]	3[11]	4[12]
Ramsar importance	To what extent is the habitat or species important for threatened or designated species?	3[13]	3[14]	4[15]
Sensitivity to change	To what extent has the habitat area/condition, species numbers or productivity of ecosystem service varied over the past 20 years as conditions change?	3[16]	2[17]	2[18]
Non-climate threats	To what extent is the asset threatened by non-climate challenges, or is the focus for management?	5[18]	3[20]	4[21]
Availability of data	To what extent are data available on the habitat area/condition, species populations or ecosystem service (for the site or region)?	4[22]	3[23]	2[24]
Total	**Sum the scores for each habitat**	**22**	**18**	**20**

(Scoring codes: 1 Very Low; 2 Low; 3 Medium; 4 High; 5 Very High)

[7] Provides livelihood support and feeding ground for birds
[8] Unique coastal habitat protection
[9] Provides livelihood support and feeding ground for birds
[10] Coastal protection and mangrove fishery
[11] Food source for mammals; bird nesting; coastal protection
[12] Feeding ground for the birds, breeding/nursery ground for fish
[13] Feeding ground
[14] Nesting and feeding ground for birds; sand dune and beach system for nesting turtles
[15] Important feeding ground – large inter-tidal area supports populations of birds
[16] The extent improved till 2018; but now large area is degraded
[17] Not much change
[18] Not much change except the area is becoming shallow
[19] Less freshwater flow; sedimentation; pollution
[20] Invasion of *Prosopis sp.*
[21] Sedimentation; lagoon is shallow; pollution
[22] Many publications available
[23] Some studies and management plan available
[24] Less studies and management plan available

2.3 Current threats and trends

The declining population of Blackbucks and the declining arrival of migratory birds are seen as issues of concern to the values of the wildlife at this Ramsar site. A decade ago, about 10,000 Greater Flamingos would visit Point Calimere Wildlife and Bird Sanctuary, but now the numbers have declined to a few thousands. Similarly, the Blackbuck population, which rose from 600 to 3000 during the 1990s has come down to less than 2000 and, in the latest estimate, to less than 1000. This section sets out the existing threats and trends for the critical assets identified for the vulnerability assessment.

2.3.1 Muthupet and Thalainayar RF

- Threats

- **FRESHWATER SCARCITY**

A lack of freshwater flows to the site due to the construction of dams and barrages upstream has resulted in significant losses in biodiversity and populations. Practically no freshwater enters the mangroves during the summer months sending the salinity in the creeks and lagoon to 45 ppt. Freshwater reaches the mangroves only during the northeast monsoon. The increasing salinity has led to near-total dominance by the salinity-resistant mangrove *Avicennia marina.* The problem of supply of freshwater will continue to degrade the mangrove biodiversity, and there is little opportunity for mitigation, given the general water scarcity in the state of Tamil Nadu and competing demands for water.

- **SILTATION OF CREEKS**

A major concern is the siltation of the lagoon and creeks. According to the local fishers, the depth of the lagoon and its width have been shrinking every year. About 20 years ago, the width of the lagoon mouth was about 2.5 km, and its depth was around 2 m. However, the width of the lagoon mouth today is only around 1 km, and its depth is no more than 1 m. The silt load is being transported from areas as far as Tuticorin by the sea currents and deposited along the Palk Strait. The heavy siltation has adversely affected the movement of fish fingerlings and prawns into the wetland and consequently the fisheries production.

Other major concerns affecting the future of the lagoon and mangroves are the increasing incidence of oyster-bed formation and the spread of the aggressive invasive plant *Prosopis sp.*, and aquaculture. Also, grazing and firewood collection are damaging the mangroves and reducing its resilience to other threats, including climate change.

- Trends

- The mangrove area increased due to restoration and better management, but after the 2018 cyclone (Gaja), the mangrove area decreased due to damage to many trees.
- The tidal water flow and freshwater flow into the mangroves have reduced.
- Mangrove species have been lost – the area once supported many mangrove species such as *Sonneratia* and *Xylocarpus,* is now dominated by *Avicennia marina.*

2.3.2 Point Calimere Sanctuary

TROPICAL DRY EVERGREEN FORESTS AND SAND DUNES

The major threats to the resident wildlife are water scarcity, cattle grazing and *Prosopis juliflora* invasion. Cattle tend to outcompete the Blackbuck and repress its population and resilience. *Prosopis sp.* encroachment in the open grasslands, the primary habitat of the endemic Blackbuck, is another serious problem in the sanctuary.

- Trends

- Erosion along the shore has increased following the tsunami, in 2004.
- The population of Blackbucks decreased but is now improving due to intensive management.
- The spread of *Prosopis sp.* is increasing despite periodic efforts at control.
- Earlier there were good surface water sources for mammals, but now they are saline, necessitating artificial provision by the Forest Department.
- The groundwater has become permanently saline.

2.3.3 Great Vedaranyam Swamp – mudflats and shallow waterbodies

PANCHANATHIKULAM WETLAND AREA, UN-SURVEYED SALT SWAMP

The major threats to wildlife are the poaching of birds and the expansion of salt pan areas.

- Trends

- The swamp is becoming increasingly shallow.
- It once supported many birds, but the populations are reducing.
- The arrivals of migratory birds are fewer and vary more substantially from one year to the next.
- Intensive management of the area is having positive results on some species and habitats.
- Poaching has reduced due to better protection.

2.4 Stakeholder roles and perceptions

Details of roles and responsibilities of stakeholders involved with the use or management of the Ramsar site and its natural resources are indicated in Table 5. The list includes official government organisations, private sectors, user groups and local communities.

Table 5 *Stakeholder analysis in Point Calimere Wildlife and Bird Sanctuary*

Stakeholder	Rights, Roles, And Responsibilities
Tamil Nadu State Wetland Authority	• Managing the wetland; coordinating the different agencies in the Ramsar site; preparing projects for the development of the Ramsar site.
WLW (Wildlife Warden - Nagapattinam) Tamil Nadu State Forest Department	• Managing the Point Calimere and Thalainayar RF; implementing projects/ schemes/protection/wildlife censuses; eco-tourism
Joint Director and Deputy Director Fisheries Nagapattinam	• Implementing fishery schemes • Implementing fishery Acts and Regulations
DFO (Thiruvarur) Tamil Nadu State Forest Department	• Conservation and management of Muthupet mangroves - mangrove restoration; eco-tourism
Assistant Director Fisheries Thiruvarur	• Implementing fishery schemes • Implementing fishery Acts and Regulations
Small salt producers	• Salt production near the Ramsar site
Farming families in Kadinelvayal	• Farming activity near the Ramsar site
Fishing/salt-producing families in Kovilthavu	• Fishing in Great Vedaranyam Swamp • Salt production near Great Vedaranyam Swamp
Fishing families in T Maravakadu	• Fishing in Muthupet mangroves • Restoring mangrove forest (with MSSRF and Forest Department)

Stakeholder	Rights, Roles, and Responsibilities
Fishing/labour for salt producers/TDEF non-timber forest produce-collecting families in Kodiakadu	• Fishing in marine water (near-shore); Great Vedaranyam Swamp • Labour work in salt pans • Collection of NTFP in Point Calimere
BNHS	• Studies related to the avifauna
DHAN	• Studies related to socio-economic assessment in Point Calimere

Table 6 summarises stakeholder perceptions of the existing climate regime and recent extreme events in Point Calimere. The villages mentioned are the locations where meetings with representative stakeholder groups were held.

Table 6 *Stakeholders' perceptions in Point Calimere*

Name of stakeholder or group	Perceptions on existing climate regime and recent extreme events, and concerns about climate change
Tamil Nadu State Wetland Authority	• Aware of climate change risks and need to manage the site for adaptation and resilience. • Gaja cyclone, in 2018, devastated the Ramsar site, and climate change will make it hard for the ecosystems to recover. • Preparing action plans for mitigation.
Tamil Nadu State Forest Department - Point Calimere	• The area is exposed to sea level rise and cyclones and disaster preparedness, and the response needs increasing attention in the management of the site • Invasion of *Prosopis* and other weeds a significant management challenge - a programme of periodic removal is implemented
Tamil Nadu State Forest Department - Muthupet	• The site is experiencing a steady degradation of mangroves due to extreme weather conditions • In particular, cyclones are causing extensive damage • Lack of freshwater supply is leading to a serious loss of diversity
Tamil Nadu State Fisheries Department	• Loss of lives and assets during cyclones is increasing - the 2018 cyclone caused extensive damage to the site • Storms are increasing in intensity as reflected in the area affected and loss in wildlife
Farming families	• The shift in the monsoon period is disrupting the farming cycle • Over time there has been an annual reduction in the number of rainy days • Drought is now frequent during the harvest period affecting income • No residual moisture for the second crop
Fishing families	• Fishers have experienced a steady reduction in fish catch per unit effort • Lagoons and canals have become silted, greatly reducing fishing areas • Cyclone intensity and frequency have increased, limiting fishing and causing damage to boats and gear
Salt producers	• Unseasonal rains affect salt production – for e.g., rain in summer • Cyclones frequently inundate the salt pans

Source: Stakeholder consultations associated with this study, see mission reports

2.5 Current management arrangements and plans

Tamil Nadu State Forest Department and Tamil Nadu State Wetland Authority are the government institutions managing the Ramsar site. For management purposes the Point Calimere Wildlife and Bird Sanctuary has been divided up into three blocks:

- Point Calimere Wildlife Sanctuary (PCWLS) and PCWLS -Block B
- Point Calimere Wildlife Sanctuary Block A
- Panchanathikulam wetland area, un-surveyed salt swamp and Thalainayar RF

The sanctuary and Block B form a part of the Vedaranyam Range and is under the overall control of the Wildlife Warden, Nagapattinam. The range management has the services of one Ranger, two Foresters (Headquarters and Section), seven Forest Guards (three for Agasthiampalli check post and the remaining four for wildlife beats and special duty) and five forest watchers.

In Point Calimere Wildlife Sanctuary Block B, the main management strategies are:

- Habitat improvement measures through the removal of invasive plant species, ensuring adequate availability of water for animals throughout the year, and forest protection from poaching and NTFP collection.
- Managing the Point Calimere Wetland Complex so that key habitats are rehabilitated and maintained
- Promoting eco-tourism through eco-development, involving local communities, publicity and awareness programmes and beach cleaning
- Research and monitoring programmes.

Point Calimere Wildlife Sanctuary Block A is one of the sections in the Muthupet Range, of Thiruvarur Division, with headquarters at Thiruvarur, which is 45 km away from the sanctuary. The Office of the District Forest Officer is at Thiruvarur. According to the management plan, the existing staff strength at the Thiruvarur Forest office is inadequate, with one Deputy Conservator of Forests, one Assistant Conservator of Forests, five Range Officers, seven Foresters and 14 Forest Guards plus support staff. In addition, workers are engaged on a daily wage basis for various purposes such as protection, monitoring and fire control. The Point Calimere Wildlife and Bird Sanctuary has only one section. There are no staff members specifically for eco-development apart from anti-poaching watchers temporarily engaged for that purpose.

In Block A the management strategies include:

- Preparation and implementation of the Shoreline Canal Management Plan
- Mangrove restoration and maintenance
- Management of the existing mangrove plantation site
- Removal of *Prosopis juliflora*
- Controlling river siltation in the Koraiyar creek by reducing bank erosion from waves and wash from boats and planting of *Rhizophora* along creek banks
- Maintenance of boundary stones
- Management of mangrove nursery
- Birds census and habitat conservation
- Maintenance of freshwater tanks in surrounding villages
- Development of eco-tourism, interpretation and conservation education activities

The management of Point Calimere Wildlife Sanctuary and Block A also covers the Panchanathikulam wetland, un-surveyed salt swamp area and the Thalainayar Reserve Forest. The main management issues are:

- Process of salt manufacturing affecting water conditions
- Spread of *Prosopis sp.* and other weeds
- Decreased freshwater inflow
- Pollution from salt works and coliform bacteria
- Oil and gas exploration
- Overfishing
- Poaching of water birds

3 CLIMATE CHANGE AT POINT CALIMERE WILDLIFE AND BIRD SANCTUARY

3.1 Current and past climate

Point Calimere Wildlife and Bird Sanctuary is located directly on the coast and is highly exposed to coastal climatic dynamics. The overall climate is hot and dry.

3.1.1 Precipitation

From October to December, the sanctuary receives rain from the northeast monsoon. Cyclonic storms are common during the monsoon period. Intermittent showers related to cyclonic formations are often experienced. An analysis of meteorological data reveals that in a normal year, 70–95% of the rain comes from the northeast monsoon, of which 40–70% may be due to cyclones. Generally, winter (January to February) and summer (March to May) are dry periods, according to IMD[21]. However, sporadic showers occur between the seasons. This area receives an average rainfall of 220 mm to 379 mm during the southwest monsoon (June to September) and 983 mm to 1,372 mm annually (Figure 5).

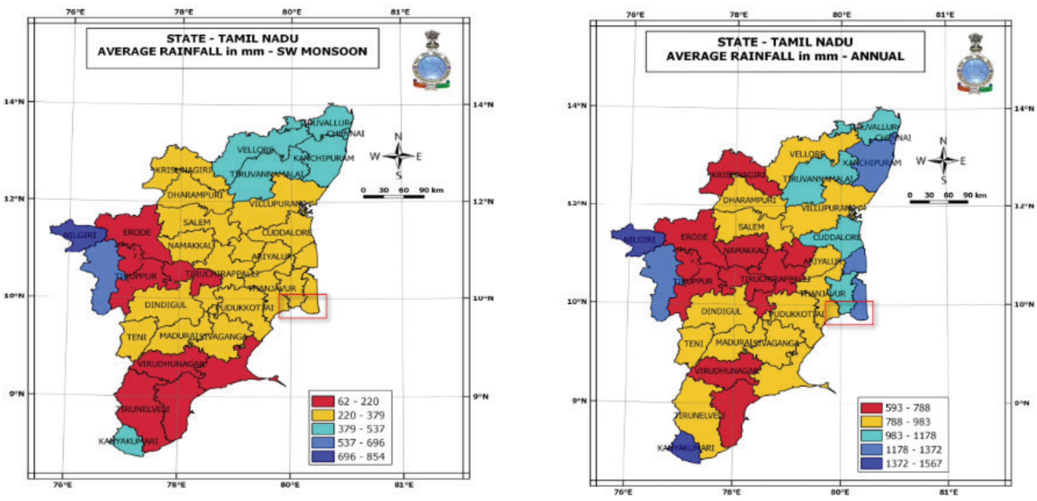

Figure 5 *Average rainfall patterns in Tamil Nadu. oint Calimere Wildlife and Bird Sanctuary is highlighted in the red box. (Source: IMD, 2020)[25].*

A more detailed analysis of rainfall data from 35 gauge stations around Point Calimere over 22 years shows that the northeast monsoon contributes 69% of the local rainfall and the southwest monsoon contributes nearly 18% of the annual rainfall (KITS, 2020)[26].

[25] India Meteorological Department, 2020. Observed Rainfall Variability and Changes Over Tamil Nadu State. Issue No. ESSO/IMD/HS/Rainfall Variability24 (2020)/48.
[26] KITS, (2020) Hydro-ecological assessment for integrated management of Point Calimere Ramsar site

There are variations in rainfall patterns from year to year and in terms of quantity of precipitation (Figure 6). Unlike the southwest monsoon, the northeast monsoon often fails to conform to a regular routine. There can be a few years when the rains arrive on time and fall in the normal pattern, but there can be years when they arrive late or do not arrive at all. The quantum of rain also varies, and there can be days of excessive or sparse rain within the same period in different years. However due to heavy downpours even during delayed years, the total quantum often tallies with the normal years.

The average frequency of rainy days in Point Calimere Wildlife and Bird Sanctuary is quite low, from 12 to 20.7 days during the southwest monsoon and 45.7 to 51.3 days annually overall, according to IMD's observations during 1989–2018 (IMD, 2020)[25]. The frequency of rainy days has increased over time but not significantly.

Figure 6 *Average monthly rainfall during 2010–2017 in Point Calimere Wildlife and Bird Sanctuary (Source: Tamil Nadu Forest Department, 2016)*[27]

3.1.2 Temperature

January is the coolest month, with the mean temperature around 25°C to 28°C. During the hottest months, May and June, the average temperature is 30°C, while the absolute maximum can reach 33°C. The annual mean temperature for the period 2010–2017 is given in Figure 7. The annual mean temperature has slightly increased during the last 10 years.

Annamalai et al. (2011), based on their study of temperature across the Cauvery basin, which includes Point Calimere

Wildlife and Bird Sanctuary, reported that the average year-to-year variation in surface temperature is about 0.4°C, with a few years warmer or cooler by 0.8°C. The temperature series obtained for the two seasons using the technique of deducting the long-term trend clearly indicate a warming tendency. For the period from 1951 to 2008, the warming is of the order of 0.7°C to 0.8°C above the natural variability. One difference is that while the warming is gradual during the southwest monsoon season, it appears to occur abruptly during the northwest monsoon season.

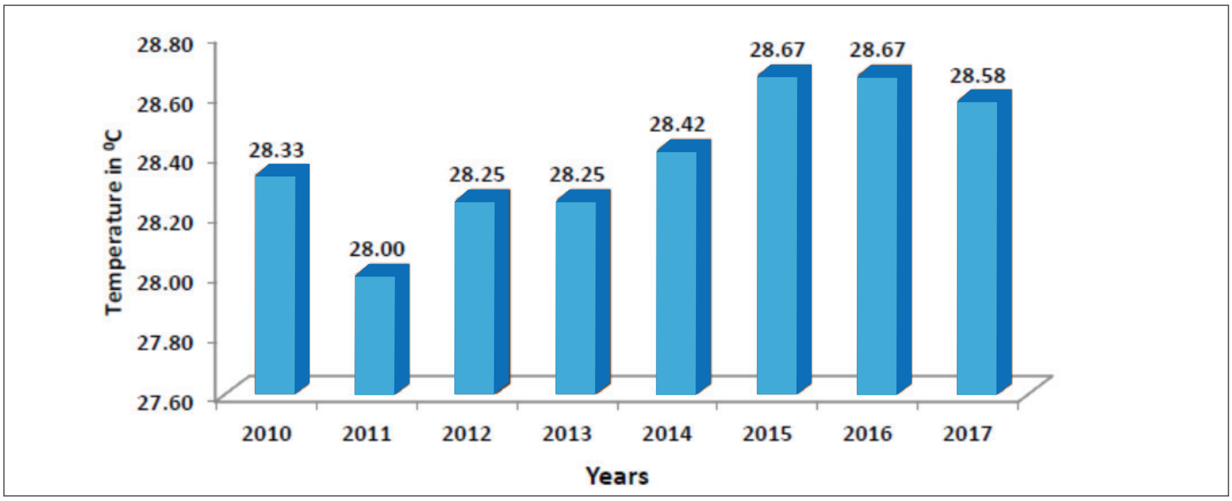

Figure 7 *Average monthly temperature during 2010–2017 in Point Calimere Wildlife and Bird Sanctuary (Source: Tamil Nadu Forest Department, 2016)*[27]

[27] Tamil Nadu Forest Department, 2016. Integrated management plan for Point Calimere Wetland Complex.

3.1.3 Extreme events and sea level rise

In Tamil Nadu, the coastal areas south of Nagapattinam district, are most vulnerable to high storm surges. In these locations, the beaches and coastal lands are gently sloping and therefore suffer deeper penetration of seawater. Protective mangroves cover is decreasing rapidly due to an increase in shrimp farming and other anthropogenic activities.

The Gaja cyclone, in November 2018, devastated thePoint Calimere Wildlife and Bird Sanctuary causing large-scale damage to the flora, fauna and infrastructure. Many trees in the sanctuary and Muthupet mangroves were uprooted. About 4 km^2 of mangrove forest cover in Tamil Nadu was lost between 2017 and 2019 due to the Gaja cyclone (Forest Survey of India, 2019).

The mean sea level rise trend off the Chennai coast is 0.32 mm/year, estimated with a 95% confidence interval of +0.37 mm/year on the basis of monthly mean sea level data for the period from 1916 to 2008[28].

3.2 Bioclimate zones

The bioclimate zone for the region around Point Calimere Wildlife and Bird Sanctuary is extremely hot and dry (Figure 8). It is likely that the climate projections for 2050 will not change this assessment and the area will remain classified as Extremely Hot and Xeric.

Figure 8: Bioclimate zone of Point Calimere Wildlife and Bird Sanctuary (Source: Adapted from Global Environmental Stratification (GEnS_v3)

3.3 Climate change projections

This section presents climate change projections for precipitation and temperature at the Point Calimere Ramsar site by 2050s, with respect to a baseline period of 1960–1990. These results were generated using an ensemble mean method of three selected GCMs: CCSM4, HadGEM2-ES and MIROC-ESM for the RCP 8.5 scenario (details of the methodology are described in Annex 1 - Section 9.1.4).

[28] http://tidesandcurrents.noaa.gov/sltrends/

3.3.1 Projections of precipitation

Projections of the total precipitation by 2050s at Point Calimere are shown in Table 7 and Figure 9-Figure 11. Overall, the precipitation is projected to increase during the SW and NE monsoon seasons and decrease during summer (March–May).

For the SW monsoon (June–September), the precipitation is projected to increase by 67.7 mm (25.3%), from 267.6 to 335.3 mm by the 2050s. A more significant increase of 113.6 mm (from 816.1 to 929.7 mm or 13.9%) is projected for the NE monsoon. The increase of rainfall during the monsoon seasons will be more significant for immediate upstream areas in the catchment (Figure 9). This increase is likely to be concentrated in more intense events.

By contrast, the precipitation is projected to decrease by 14.1 mm during the summers of the 2050s, from 131.1 mm to 117.0 mm (10.7%). No remarkable change is projected for winter (January–February).

Table 7 Projections of seasonal precipitation change by the 2050s at the PoinPoint Calimere Wildlife and Bird Sanctuary

Season	Baseline 1960–1990 (mm)	Projection 2050s (mm)	Change (mm)	Change (%)
Winter (January–February)	86.8	87.5	0.6	0.7
Summer (March–May)	131.1	117.0	-14.1	-10.7
SW monsoon (June–September)	267.6	335.3	67.7	25.3
NE monsoon (October–December)	816.1	929.7	113.6	13.9

Photo credit: GIZ_Prasanth

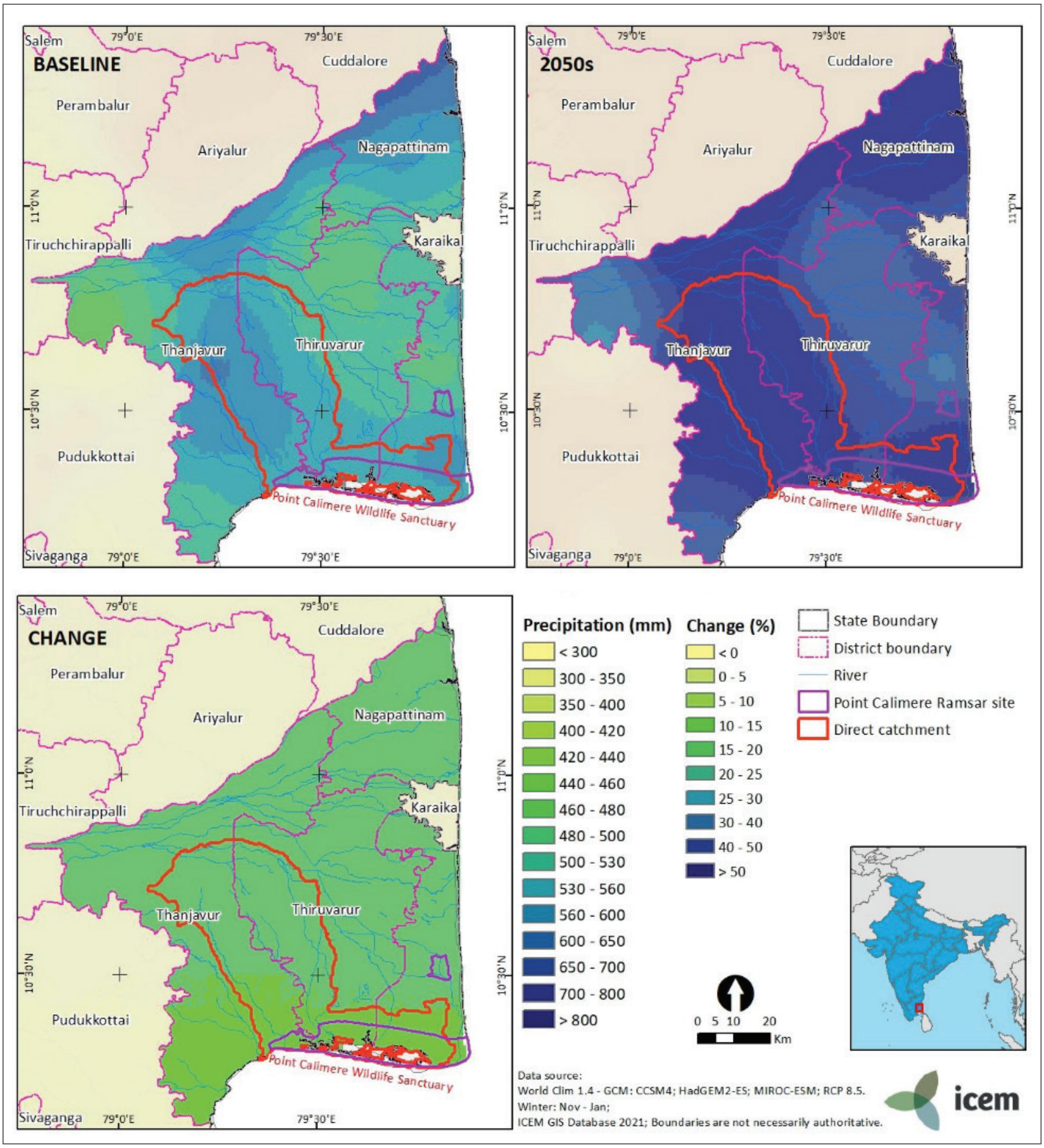

Figure 9 *Projections of precipitation change during monsoons at Point Calimere Wildlife and Bird Sanctuary*

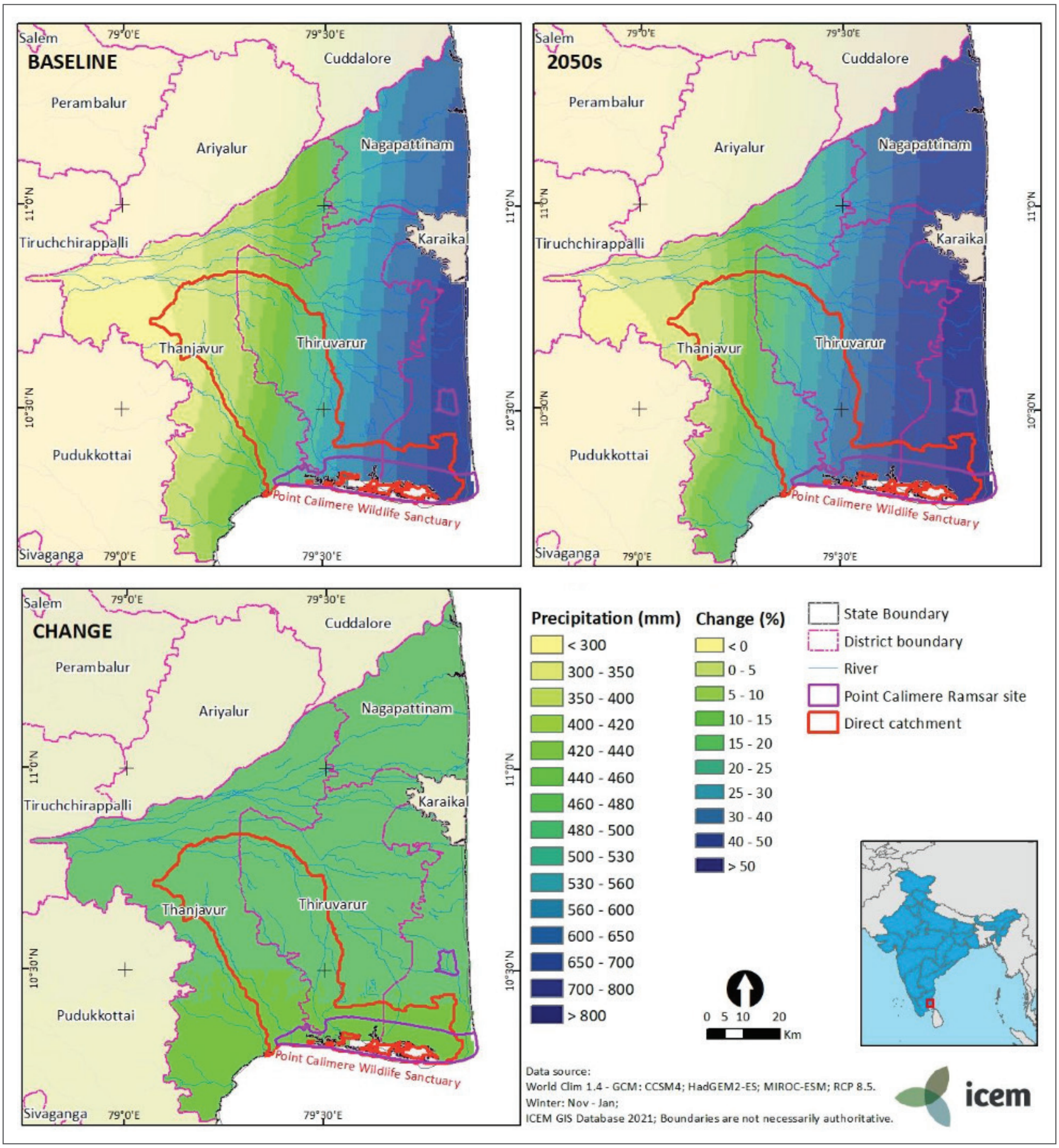

Figure 10 Projections of precipitation change during winter (January–February) at Point Calimere Wildlife and Bird Sanctuary

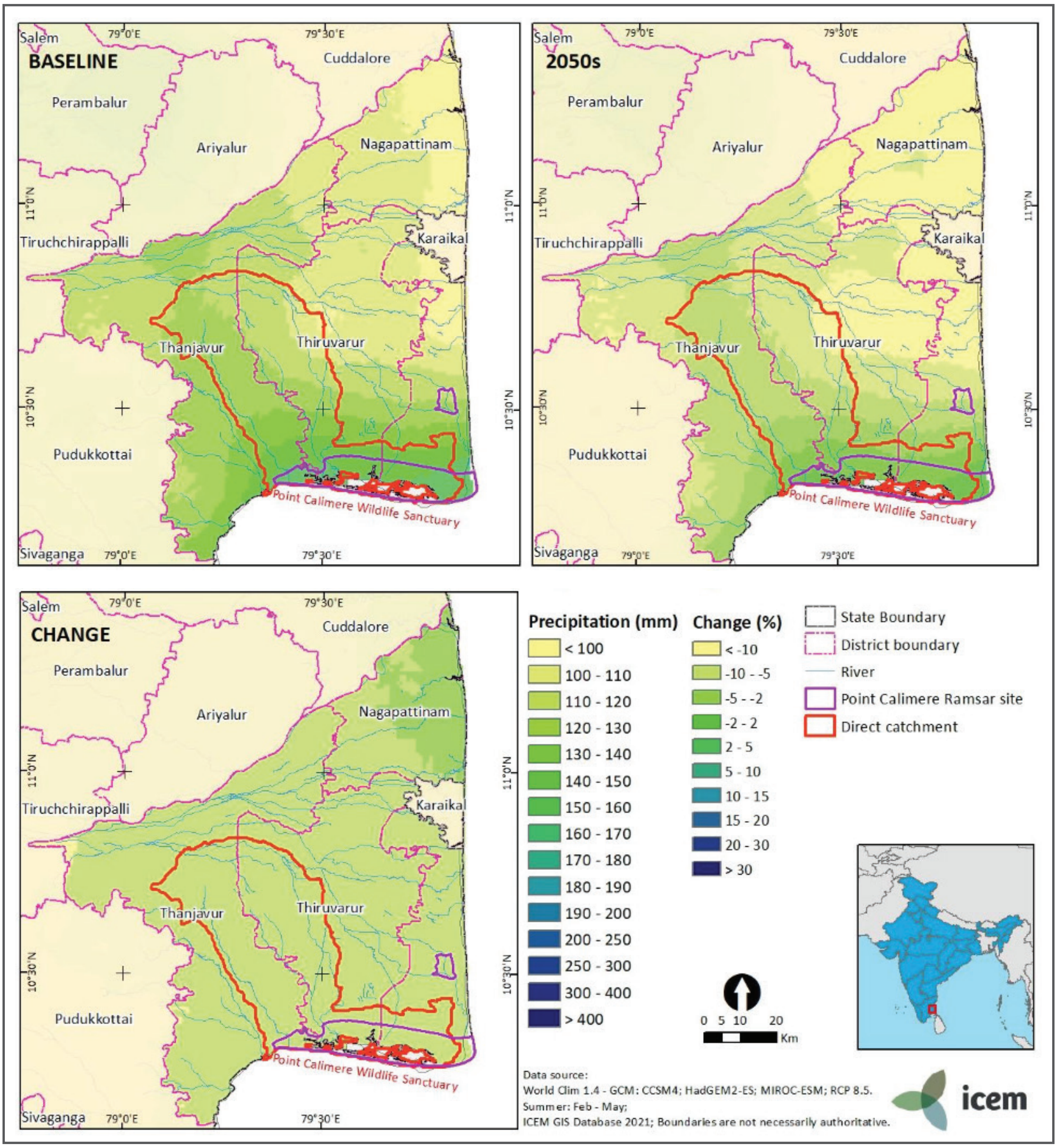

Figure 11 *Projections of precipitation change during summer (March–May) at Point Calimere Wildlife and Bird Sanctuary*

3.3.1 Projections of temperature

Projections for the average maximum temperature by the 2050s at the Point Calimere Wildlife and Bird Sanctuary are shown in Table 8 and Figures 12-14 Error! Reference source not found.12-Figure 14. Overall, the average maximum temperature is projected to increase by 1.8ºC to 2.2ºC by the 2050s.

Both winter (January–February) and summer (March–May) at Point Calimere will be warmer by 2050. The average maximum temperature is projected to increase by 1.8ºC (from 29.5ºC to 31.2ºC) during winter and by 2.1ºC (from 33.7ºC to 35.8ºC) during summer. Summer will be an extreme season with limited rainfall and higher temperatures, which will stress the forests and associated species.

The average maximum temperature is projected to significantly increase during the SW and NE monsoons, with an increase of 2.2ºC (from 34.0ºC to 36.1ºC) during the former and 1.9ºC (from 29.7ºC to 31.6ºC) during the latter.

Table 8 *Projections of seasonal temperature change by 2050s at Point Calimere Wildlife and Bird Sanctuary*

Season	Baseline 1960–1990 (ºc)	Projection 2050s (ºc)	Change (ºc)
Winter (January–February)	29.5	31.2	1.8
Summer (March–May)	33.7	35.8	2.1
SW monsoon (June–September)	34.0	36.1	2.2
NE monsoon (October–December)	29.7	31.6	1.9

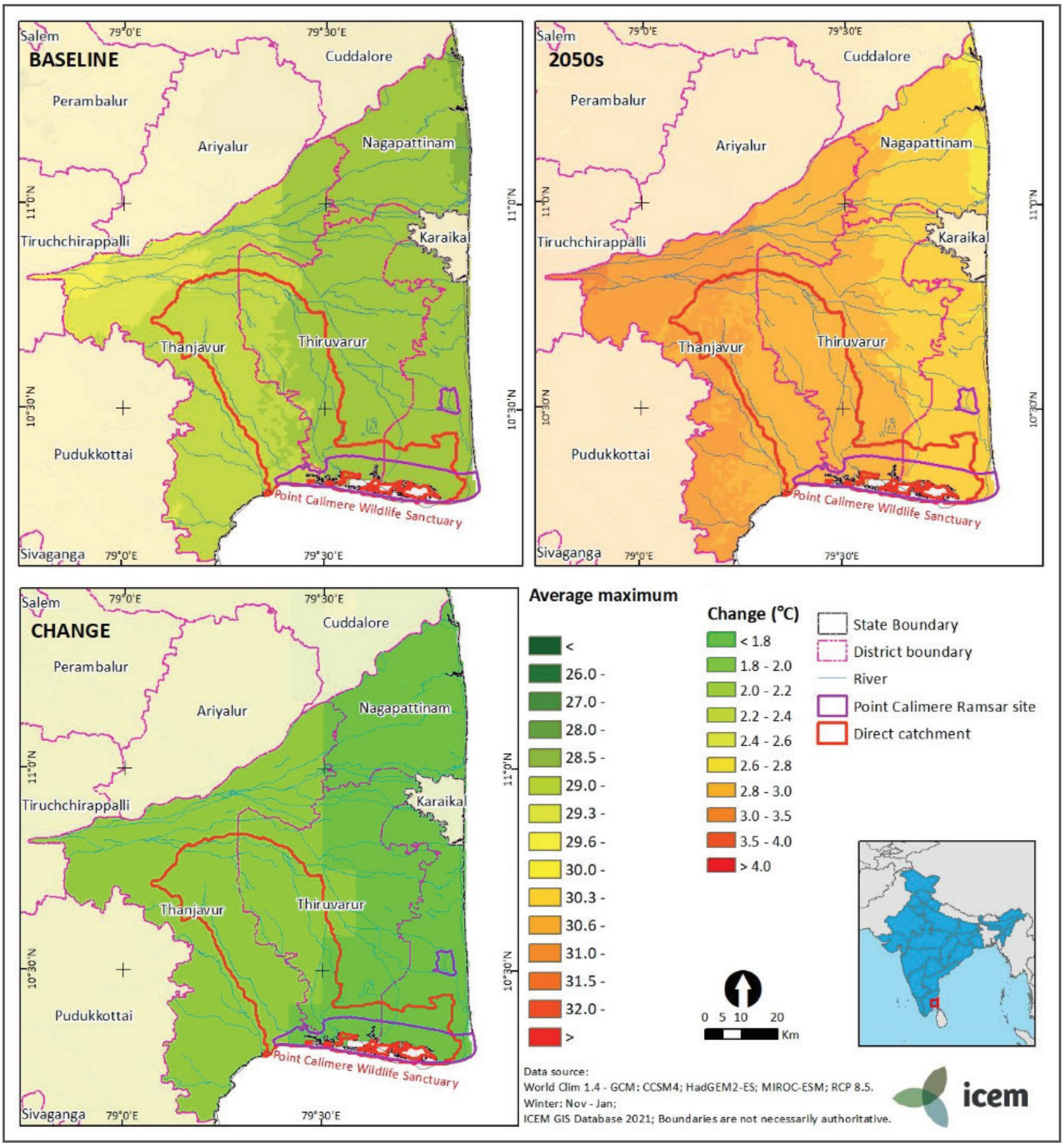

Figure 12: Projections of change in temperature during winter (January–February) at Point Calimere Wildlife and Bird Sanctuary

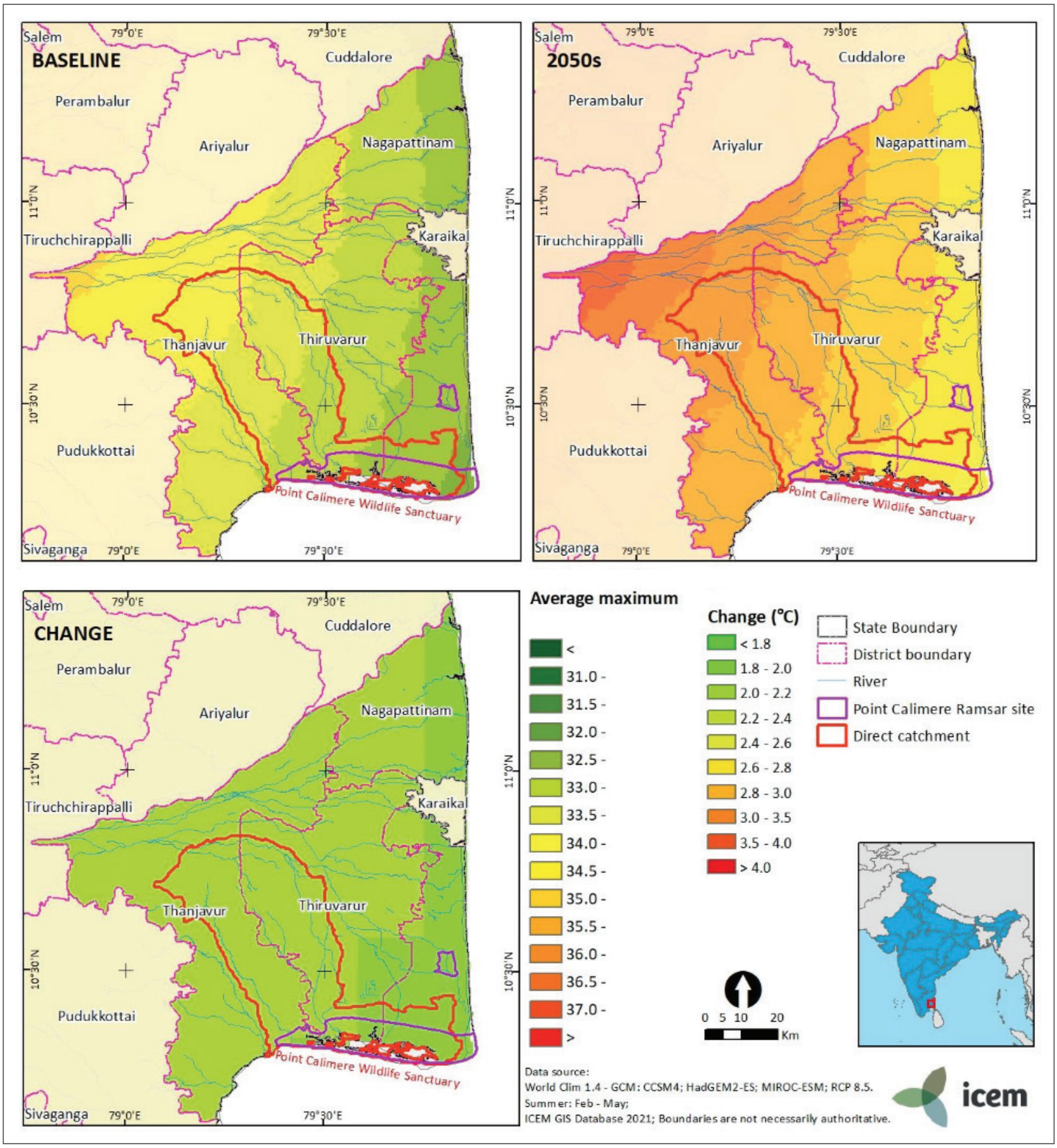

Figure 13 *Projections of temperature during summer (March–May) at Point Calimere Wildlife and Bird Sanctuary*

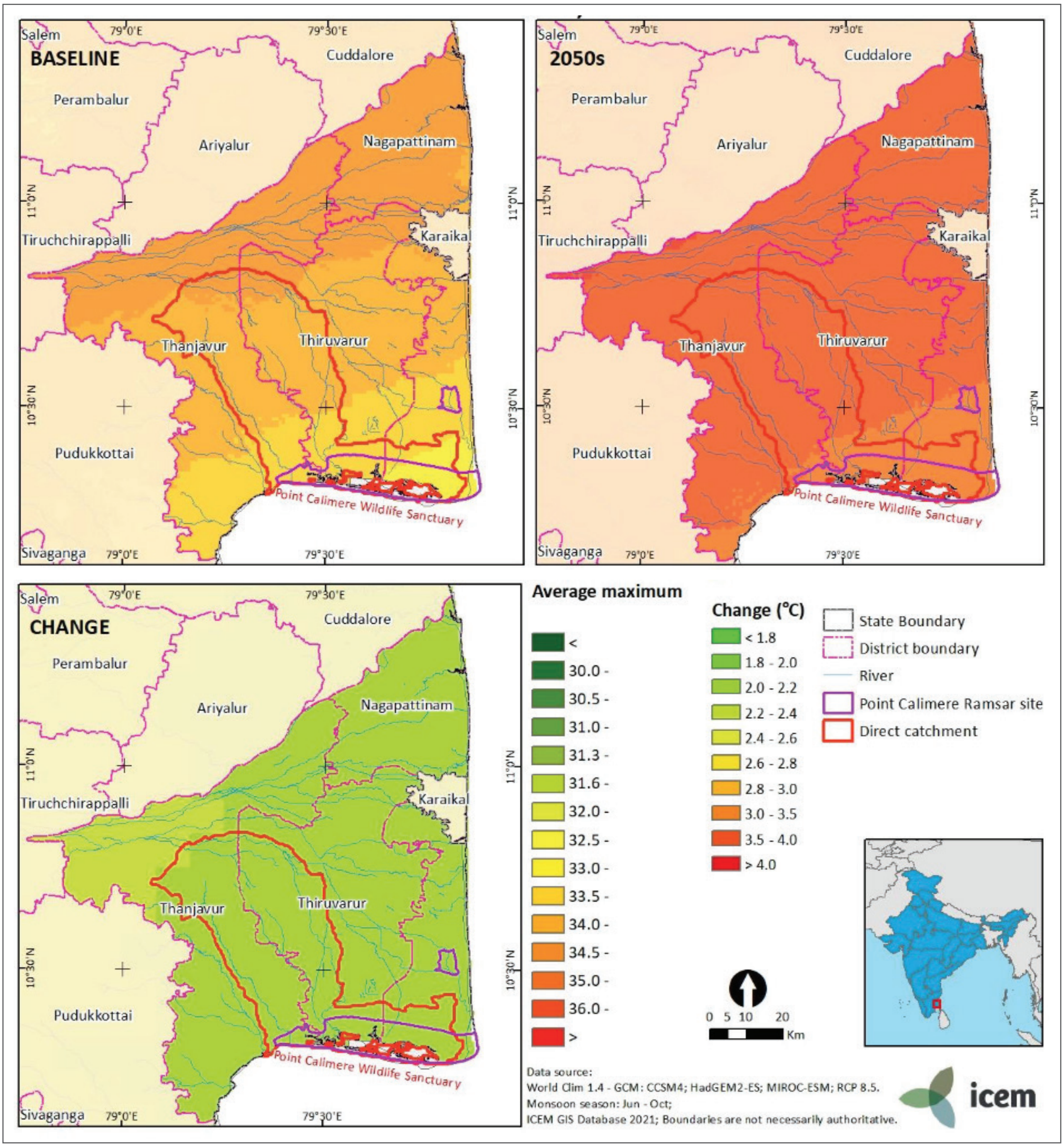

Figure 14 *Projections of temperature during monsoons (June–December) at Point Calimere Wildlife and Bird Sanctuary*

3.3.3 Extreme events and sea level rise

Point Calimere Wildlife and Bird Sanctuary is likely to be impacted by more extensive periods of drought during summer (March–May), caused by the increase in temperature and the decrease in rainfall during this period.

With climate change, extreme cyclones and storm surges are expected to increase in frequency and intensity. The results from a recent study (Ahammed & Pandey, 2020)[29] indicate that this area has a very high risk of increased frequency of cyclones and a low to moderate risk of storm surges up to 5 m (Figure 15). The rainfall is expected to be concentrated in more intense events that cause a higher risk of floods.

[29] Ahammed, K.B. and Pandey, A.C., 2020. Climate Change Impacts on Coastlines in Eastern Coast of India: A Systematic Approach for Monitoring and Management of Coastal Region.

Sea level rise is an important consequence of climate change for societies and the environment. The mean sea level at the coast is defined as the height of the sea with respect to a local land benchmark, averaged over a period that is sufficiently long enough for fluctuations caused by waves and tides to be largely removed. Point Calimere Wildlife and Bird Sanctuary is projected to be at high risk from sea level rise (Figure 15).

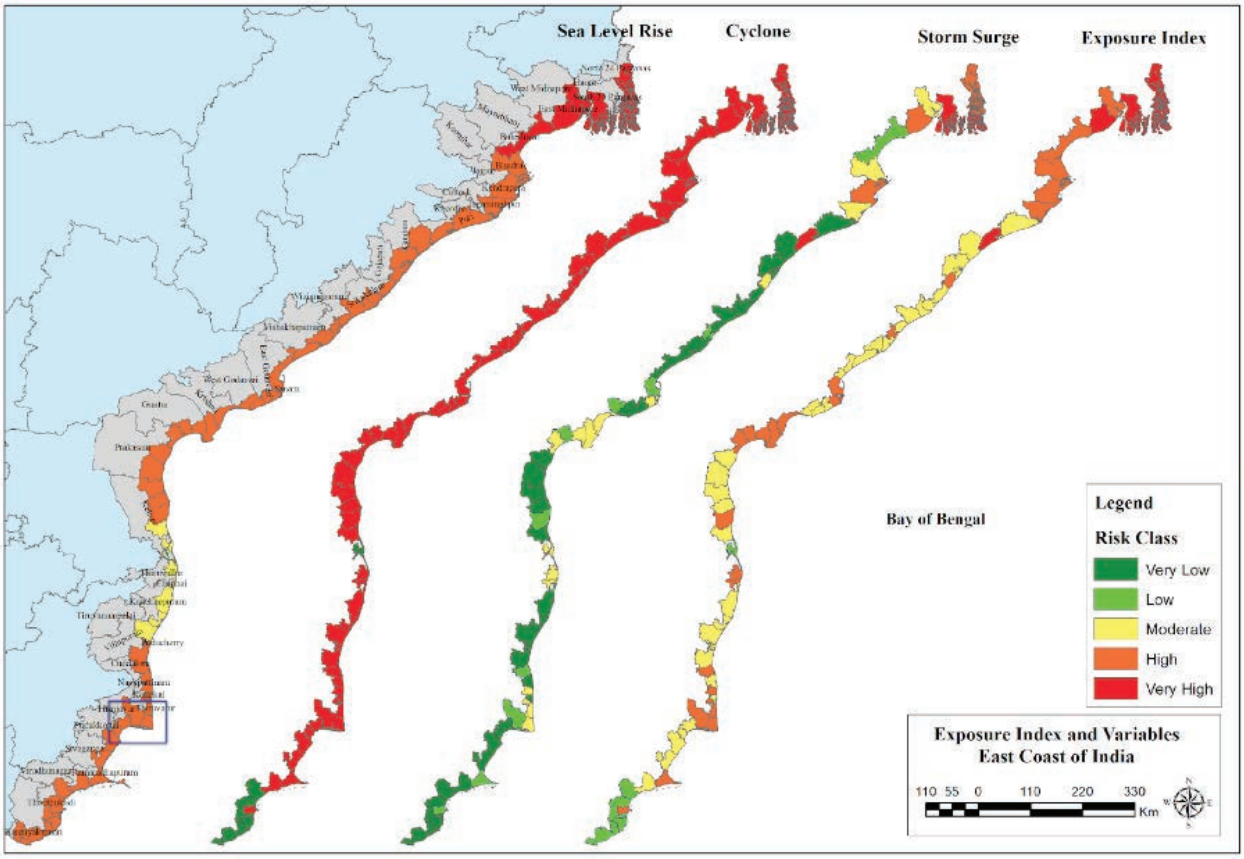

Figure 15 *Risks of cyclones, storm surges and the sea level rise due to climate change along the eastern coast of India. Point Calimere Wildlife and Bird Sanctuary is in the blue box. (Source: Ahammed & Pandey, 2020)*

The hydro-ecological study on Point Calimere Wildlife and Bird Sanctuary commissioned by GIZ calculated the land cover categories that would be inundated in the area by a 1 m rise in sea level and those that would be affected by 2 and 3 m storm surges. The total land area affected by a sea level rise of 1 m would be 37.19 km^2, of which mangroves make up 3.23 km^2 and tidal flats 12.36 km^2 (see[30])

Table 9 *Areas of land cover categories in the Point Calimere area that will be inundated by a 1 m sea level rise and by 2 and 3 m storm surges*

Land Cover Category	1 M Rise (Km^2)	2 M Surge (Km^2)	3 M Surge (Km^2)
Cultivated land	1.54	7.42	20.38
Waterbodies	8.53	9.68	12.35
Aquafarms	0.58	0.88	1.62
Lagoon and estuary	4.98	6.13	8.23
Barren land	2.15	3.32	5.78
Scrub forest	0.02	0.05	0.08
Mangrove	3.23	4.34	5.87
Tidal flats	12.3	16.87	27.56

[30] Tamil Nadu Forest Department, 2016. Integrated management plan for Point Calimere Wetland Complex.

Table 9 Areas of land cover categories in the Point Calimere Wildlife and Bird Sanctuary area that will be inundated by a 1 m sea level rise and by 2 and 3 m storm surges

Land Cover Category	1 M Rise (Km^2)	2 M Surge (Km^2)	3 M Surge (Km^2)
Salt pans	0.30	0.48	1.98
Settlement	1.48	2.21	4.65
Scrub land	2.02	3.15	5.23
TOTAL	**37.19**	**54.53**	**93.73**

3.3.4 Coastal Vulnerability Index

The Indian National Centre for Ocean Information Services (INCOIS) calculated the Coastal Vulnerability Index (CVI), which combines the coastal risks due to future sea level rises on the basis of physical and geological parameters for the Indian coast using parameters such as the tidal range, wave height, coastal slope, coastal elevation, shoreline change rate, geomorphology and historical rate of relative sea level change. The method has been used to create a CVI map for the Tamil Nadu coast, which is shown in Figure 16[31]. 21% of the coast of Tamil Nadu is considered to be 'very highly' vulnerable to sea level rise, which includes the exposed beaches around Point Calimere Wildlife and Bird Sanctuary. The area around the Great Vedaranyam Swamp has been classified as 'highly' vulnerable to sea level rise, with Muthupet being classified as having 'low' vulnerability.

Photo credit: Prasanth

[31] Rajan, Sasi Mary Priya & Np, Mohammedali & Tiwari, Surya Prakash & Vengadasalam, Radhakrishnan. (2019). Mapping and analysis of the physical vulnerability of coastal Tamil Nadu. Human and Ecological Risk Assessment. 10.1080/10807039.2019.1602752.

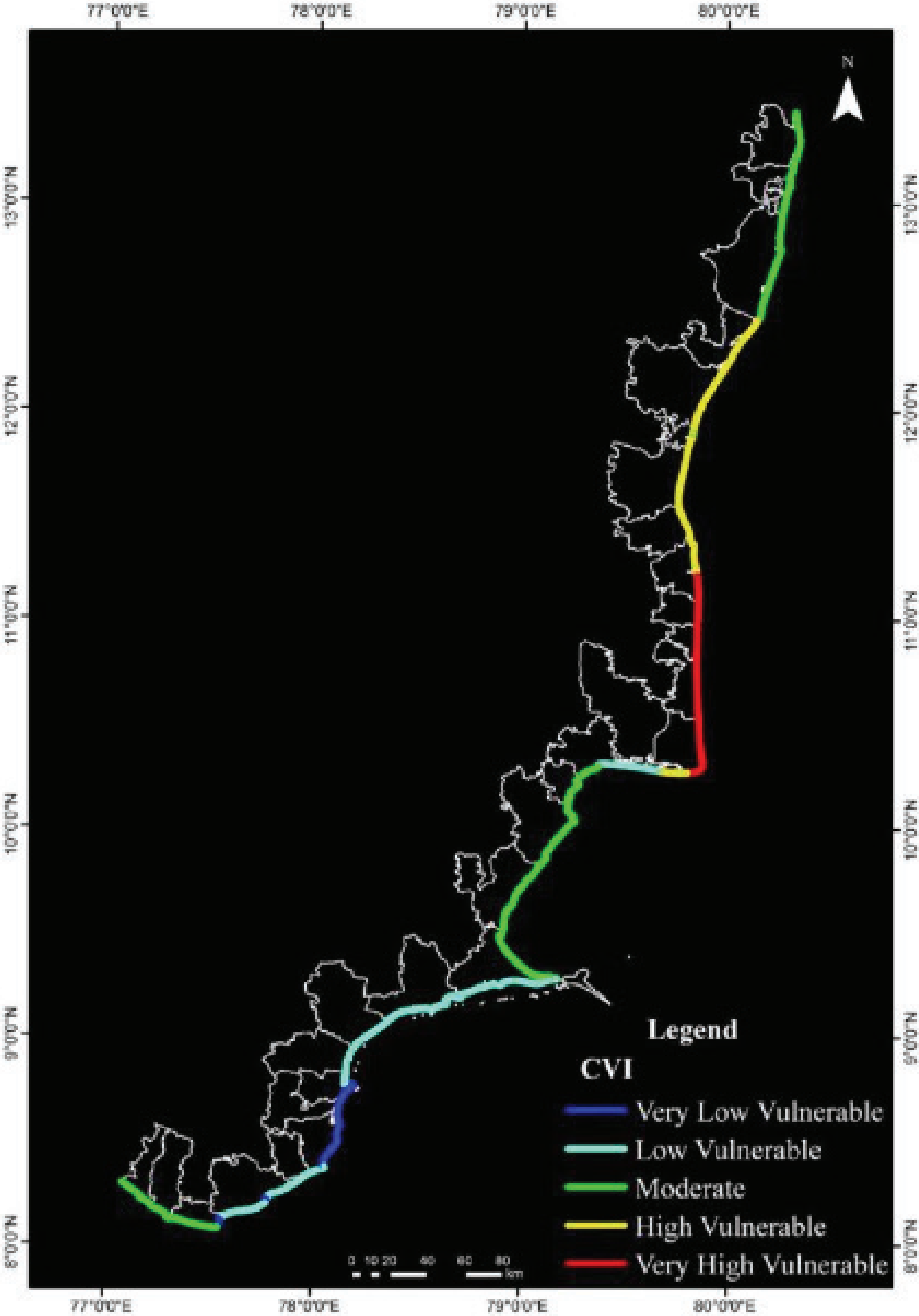

Figure 16 *Coastal Vulnerability Index for the Tamil Nadu coast*
Source: Rajan et al., 2019

4 IMPACT AND VULNERABILITY ASSESSMENT

4.1 Vulnerability summary of the Point Calimere Ramsar site

The climate of Tamil Nadu is mainly of the tropical semiarid type. The geographical location of Tamil Nadu makes it one of the most vulnerable maritime states in India, particularly to tropical cyclones and their associated storm surges[32]. The coastal districts of the state are frequently subjected to extreme weather conditions of flooding and severe droughts, some areas chronically and others periodically. The areas along the coast of Tamil Nadu have many significant ecosystems such as mangroves, mudflats, estuaries, Tropical Dry Evergreen Forests (TDEF), coral reefs, seagrass beds and lagoons. These ecosystems are highly productive and are 'highly' vulnerable to climate change impacts, particularly sea level rise and cyclones. The assessment of climate change vulnerability was conducted for important assets such as the mangroves, mudflats and associated shallow waterbodies and Tropical Dry Evergreen Forests (TDEF) of the Point Calimere Wildlife and Bird Sanctuary. The vulnerability scores of those assets is given in Figure 17. The full vulnerability assessment matrix of each asset appears as Annex 2 of this report.

Threats	Muthupet and Thalinayar Mangroves					Point Calimere Sanctuary					Great Vedaranyam swamp				
	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul
Precipitation															
Increase of rainfall during SW Monsoon (Jun–Sep) and NE Monsoon (Oct-Dec)	H	L	M	H	M	L	M	M	L	M	H	M	H	H	M
Decrease of rainfall during summer (Mar-May)	L	L	L	M	M	L	M	M	L	M	L	M	M	M	M
Temperature															
Increase of temperature during SW Monsoon (Jun–Sep)	L	L	L	M	M	H	M	H	L	H	H	H	H	L	H
Increase of temperature during NE Monsoon (Oct-Dec)	L	H	M	M	M	M	M	M	L	M	H	H	H	L	H
Increase in temperature during summer (Mar to May)	L	H	M	L	M	H	H	H	VL	VH	H	VH	VH	L	VH
Increase of temperature during winter (Jan-Feb)	L	H	M	M	M	L	M	M	L	M	L	L	L	L	M
Extreme events															
Sea level rise	H	H	H	L	H	H	VH	VH	L	VH	H	H	H	L	H
Cyclones	H	H	H	H	M	VH	VH	VH	VL	VH	VH	VH	VH	L	VH
Storm surge	M	H	M	L	M	M	VH	H	VL	VH	M	VH	H	L	H

Note: **Exp** = Exposure, **Sen** = Sensitivity, **Imp** = Impact, **Adc** = Adaptive Capacity, **Vul** = Vulnerability

Scoring code: VH Very High H High M Medium L Low VL Very Low

Figure 17 *Vulnerability scores of the key habitats of Point Calimere Wildlife and Bird Sanctuary*

Although the scores sometimes indicate 'medium' vulnerability to climate change, the synergistic impacts of climate changes on all three habitats and their component assets are likely to be 'highly' negative. Seasonal differences will be 'more' extreme, with drier and hotter dry seasons and wetter and hotter monsoon seasons so that the positive and negative impacts will tend to offset each other to some extent. Overall, they will reinforce existing non-climate threats and negative trends. The synthesis of existing trends and pressures overlaid with climate change that follows the detailed assessments provides a more complete picture of the 10-year trends and impacts on the habitats and their assets.

[32] Bal, P.K., Ramachandran, A., Geetha, R., Bhaskaran, B., Thirumurugan, P., Indumathi, J. and Jayanthi, N., 2016. Climate change projections for Tamil Nadu, India: Deriving high-resolution climate data by a downscaling approach using PRECIS. Theoretical and Applied Climatology, 123(3), pp. 523–535.

- Muthupet and Thalainayar mangrove areas

Although all the projected rainfall and temperature impacts were found to be 'medium', the long-term pressure on the mangroves due to climate change and other pressures will lead to an increase in degraded areas, with lower recovery and re-colonisation of the trees after damage from storm events and sea level rise. The dominance of *Avicennia sp.* will become more pronounced, and the progressive loss of *Rhizophora* and *Sonneratia* species will continue. Degraded areas will continue to expand, and the capacity of the mangrove forest to sequester carbon will be further reduced.

- Point Calimere Wildlife and Bird Sanctuary

The Point Calimere Wildlife and Bird Sanctuary which is a habitat for tropical dry evergreen forests and the endangered blackbucks will be affected by the increase in the temperature and rise in extreme events like cyclones, sea-level rise, and storm surges. The extent of grassland will be reduced by increased salinisation. Biodiversity, especially flora will also be affected by the increase in soil and water salinity in the sanctuary. The change in floral composition especially the loss of grasslands and the spread of hardy invasive species like *Prosopis sp.* will reduce fodder availability for herbivores.

- Great Vedaranyam swamp (GVS)

The mudflats and shallow waterbodies in the Great Vedaranyam Swamp (GVS) are an important feeding area for migratory birds such as flamingos. The swamp also supports salt pans and aquaculture ponds. The swamp provides finfish and shellfish, which contribute to the livelihoods of the local fishing community. In the fringe areas, salt marshes and *Prosopis sp.* are found to a large extent. The continued expansion of *Prosopis sp.* will have a negative influence on the GVS ecosystem.

4.2 Mangrove Habitat

Muthupet and Thalainayar constitute the mangrove wetlands of the Ramsar site. The Muthupet mangroves are at the southern end of the Cauvery delta, occupying approximately 12,000 ha, including a 1700 ha lagoon. The extent of the healthy mangrove forest is only 1855, ha with about 7178 ha mostly degraded[33]. The Thalainayar mangroves, in the estuary of River Adappar, are situated approximately 18 km north of Point Calimere. *Avicennia marina* is the dominant and keystone species in these wetlands. The mangroves provide livelihood support to the coastal fishers and a habitat for many migratory birds. The climate change assessment identified impacts on key species of the ecosystem that need to be addressed as part of the site adaptation plan.

4.2.1 Impact of precipitation change

- Increasing precipitation during monsoon seasons

The projected increase in the rainfall in both the SW and NE monsoon seasons brings more freshwater and sediments into the mangrove wetlands, resulting in a reduction in salinity, enabling land building processes from sedimentation. The mangrove health will improve due to nutrient-rich freshwater and sediments at this time of year. The density and canopy cover will increase due to favourable conditions that, in turn, will enhance coastal protection against disasters such as cyclones and reduce coastal erosion due to rising sea level. The fruiting season of *Avicennia marina,* which is the dominant species in these wetlands, coincides with the NE monsoon. The less saline water favours the germination of mangroves and halophytes. The floods and tides during the monsoon seasons will help the dispersal of seeds, their germination and establishment. However, the rainfall during the cyclones will affect flowering and fruiting, and premature shedding of fruits will occur. The plankton will increase in the mesohaline brackish water conditions in the lagoon (Mullipallam) of Muthupet due to the reduction in salinity as well as increased availability of dissolved nutrients. The juvenile fish, which are dependent on plankton, will increase, leading to enhanced fish catch, which in turn will improve the livelihood of fishers.

[32] Gupta, G.V.M., Natesan, U., Murthy, M.R., Kumar, V.S., Viswanathan, S., Bhat, M.S., Ray, A.K. and Subramanian, B.R., 2006. Nutrient budgets for Muthupet lagoon, southeastern India. Current Science, pp. 967–972.

The vulnerability of the mangroves of Point Calimere Wildlife and Bird Sanctuary will be 'medium' due to the increase in rainfall, with generally positive impacts, even though there is a decrease in the rainfall, coupled with increase in temperatures during the summer.

- Decreasing precipitation during summer

The projected reduction in rainfall during summer will increase soil salinity and evapotranspiration in the mangroves, reducing the photosynthetic efficiency. In recent years, the mangroves in Tamil Nadu, particularly those in Muthupet, have experienced shoot dieback because of increasing salinity and temperatures and a lack of tidal water flows. Even the highly saline-tolerant *Avicennia marina* has been affected. About 150 years ago, in Muthupet the true mangrove species belonging to the family *Rhizophoraceae* were dominant, but now they are locally extinct due to reduced freshwater flows. Many saline-sensitive species have been lost, and now *Avicennia* makes up more than 95% of the mangrove forests. Palynological studies[34] carried out in the Muthupet mangroves by Tissot (1987) showed that the species belonging to the genera *Rhizophora* and *Sonneratia,* which occurred there, have disappeared over the last 200 years[35]. There is also a large-scale invasion of *Prosopis juliflora,* an exotic thorny plant, and *Suaeda nudiflora*, a halophyte, along the periphery of the site, indicating a steady change in the composition of the vegetation. The increase in temperature will result in the further expansion of these invasive species.

Already the degraded area in Muthupet mangroves is more than 7000 ha[36]. Site-specific and species-specific adaptation plans will be needed to reduce the extent of the degraded area to minimise the climate change impacts. The vulnerability of the mangroves in this area will be 'medium', with overall negative impacts due to the reduction in rainfall during summer.

4.2.1 Impact of temperature change

- Increasing temperature during SW and NE monsoon seasons

The projected increase in temperature during the SW monsoon will increase the soil salinity levels due to evaporation. However, the impact will be less or offset to some extent due to the increase in precipitation during that period. Similarly, the increase in temperature during the NE monsoon will impact young seedlings, particularly in already degraded fringe areas. A small increase in temperature may not adversely affect flowering but may change the reproductive cycle of the plants and thus alter the duration between flowering and the fall of ripe seeds. The arid climate that prevails in Tamil Nadu is largely favouring mono-specific stands of *Avicennia marina,* as this species is resistant to high temperatures (Kathiresan, 2017)[37].

The vulnerability of the mangroves will be 'medium' due to the increase in temperature during the SW and NE monsoon seasons.

- Increasing temperature during summer

The projected increase in temperature during summer will increase the water salinity and soil salinity, which will adversely affect the mangrove growth and health. The increase in soil salinity (hypersaline conditions) in Muthupet leads to shoot dieback. The saline-sensitive species belonging to the family Rhizophoraceae will be lost from the ecosystem. The increase in water temperature will enhance the metabolic rate, leading to quicker growth of fish, which will have some beneficial impact on livelihoods, provided sufficient food is available for the fish in the lagoon as well as in the mangrove area. The photosynthetic rate will be less during summer due to closure of stomata, which is an adaptation in plants for reducing the loss of water due to evapotranspiration. Evapotranspiration rates are affected by a variety of factors including humidity, temperature and wind speed. The mangroves in the Point Calimere wildlife and bird sanctuary will experience 'medium' vulnerability due to the increase in temperature during summer.

[34] The study of plant pollen, spores, and certain microscopic planktonic organisms

[35] Tissot, C., 1987. Recent evolution of mangrove vegetation in the Cauvery delta: A palynological study. Journal of Marine Biology Association of India, 29, 16–22

[36] Gupta, G.V.M., Natesan, U., Murthy, M.R., Kumar, V.S., Viswanathan, S., Bhat, M.S., Ray, A.K. and Subramanian, B.R., 2006. Nutrient budgets for Muthupet lagoon, southeastern India. Current Science, pp. 967–972.

[37] Kathiresan, K. (2017). Mangroves in India and Climate Change: An Overview. 10.1007/978-4-431-56481-2_3.

- Increasing temperature during winter

The increase in temperature during January–February could increase the soil salinity, which may affect young mangrove seedlings. This temperature increase in winter will make the mangroves vulnerable to a 'medium' extent.

4.2.3 Impact of extreme events

- Sea-level rise on mangrove wetlands

The mangroves in Muthupet are in low-lying coastal areas and are vulnerable to sea level rises (Kathiresan, 2017). If mangroves are fully submerged, their extent is reduced. The vertical elevation of the mangrove floor will reduce due to a reduced sediment supply from the rivers. The hydro-ecological study on Point Calimere Wildlife and Bird Sanctuary developed inundation maps for the Point Calimere area and concluded that for a 1 m rise in the sea level, 37.19 km^2 of the area will be inundated, including 323 ha of the mangroves in Muthupet and Thalainayar. The area of the healthy mangroves in Muthupet is estimated at 1855 ha and that of the degraded mangroves at 7178 ha. A sea level rise of 1 m will likely decrease the area of the healthy mangroves by 17.4%. In Tamil Nadu, the mangroves are less dense due to the reduced river water flows and monsoon failure, and hence the mangrove areas are vulnerable to sea level rise. The most vulnerable mangrove species in this regard are *Avicennia* and *Sonneratia* because their low-level pneumatophores are fully covered by the rising levels, while the stilt roots of *Rhizophora spp.* project above the raised water levels (Kathiresan, 2017).[37]

The movement of mangroves into elevated areas will be inhibited by the expanding invasion of *Prosopis* and halophyte species such as *Suaeda.* Mangroves will not colonise these areas. Beyond this zone are areas are under private ownership that are used for aquaculture. The mangrove loss will directly impact the fishers due to the reduction in feeding grounds of fishes. A sea-level rise will increase the vulnerability during cyclonic storms as surges reach far inside the landward area. The mangroves in the Point Calimere Wildlife and Bird Sanctuary will have a 'high' vulnerability to the projected sea level rise.

- Cyclones

The mangrove wetlands along the east coast of India are already highly vulnerable to cyclones. Climate change will increase the frequency and intensity of cyclones, as evident during the November 2018 (Gaja) cyclone. According to a Forest Survey report (FSI, 2019)[38], an area of about 3 km^2 was lost in Muthupet during the cyclone. Although *Avicennia* has high resilience to cyclones, its recovery has failed in the sparse degraded areas in Muthupet. In the Thalainayar mangroves, the damage was comparatively less due to its proximity to the coast and short height and dense cover. The northern part of Muthupet has comparatively dense mangroves, which recovered, while most of the sparse mangroves on the southern side were completely uprooted.

The *Avicennia* species is able to regenerate more easily after a cyclone compared with the *Rhizophora*[39] species. However, in Muthupet the recovery of the *Avicennia* species has been much less. Local villagers observed that the bark of *Avicennia* was damaged and stripped away by the wind. The root systems of uprooted trees were completely exposed, which constrained the recovery. Natural regeneration of mangroves will take considerable time, requiring intervention by the Forest Department involving large-scale replanting to improve the cover and density. The degradation of forest conditions reduces the effectiveness of the forest as a bio-shield against future cyclones. A reduction in the extent also reduces the fisheries potential and the extent of the feeding ground of avifauna. Loss of carbon sequestration capacity and progressive release of CO_2 into the atmosphere is likely as these mangroves continue to be degraded by successive cyclones. The recent estimation of carbon in the Muthupet mangroves indicated that the carbon sequestration potential has increased to 60% from 2000 to 2017 (in 17 years)

[38] https://fsi.nic.in/isfr19/vol1/chapter3.pdf

[39] Kandasamy, K., 2017. Mangroves in India and climate change: An overview, in: Impact of Climate Change, Land Use and Land Cover, and Socio-economic Dynamics on Landslides. Pp. 31–57. doi:10.1007/978-4-431-56481-2_3

Narmada & Annaidasan, 2019[40]. The mangroves in the Point Calimere Ramsar site were found to have 'medium' vulnerability to cyclones.

- Storm surges

Storm surges will cause extensive changes in the topography and geomorphology of the coastal area, which will affect the free flow of water into the mangroves. Storm surges increased the siltation of natural and man-made canals. Storm surges will drive in sand from the sea, reducing the lagoon area and its value as a feeding ground for the avifauna. Water stagnation for a prolonged period in the lower areas will suffocate mangroves roots and kill trees. The coastal area will become more salinised. The vulnerability of the mangroves to storm surges was scored as 'medium'.

4.3 Habitats of Point Calimere Wildlife and Bird Sanctuary

Point Calimere Wildlife and Bird Sanctuary is one of the important habitats of the Tropical Dry Evergreen Forest (TDEF), which covers about 15 km2. About 364 flowering plants have been identified, of which Manilkara hexandra (Palai in Tamil) is the dominant dry evergreen tree species of the sanctuary. *Lannea coromandelica* is the only deciduous species found in this forest. The sand dunes are largely colonised by *Prosopis juliflora* and *Calotropis gigantea.* Sporadic nesting of Olive Ridley sea turtles is noticed along the sandy beach. Point Calimere Wildlife and Bird Sanctuary is home to the largest population of the endemic Blackbuck *(Antilope cervicapra)* in south India. Other animals of the sanctuary include the Spotted Deer *(Axis axis),* Wild Boar *(Sus scrofa)* and Jackal *(Canis aureus).* The Spotted Deer, feral-horse *(Equus caballus)* and the Bonnet Macaque *(Macaca radiate)* were introduced into the sanctuary.

Though agriculture, fisheries and salt production are the main sources of livelihood around the bird sanctuary, cattle rearing also supports villagers during the lean period of farming. The people in villages nearby collect non-timber forest products from the sanctuary. These practices are now prohibited but have not been fully eliminated. Villagers mainly catch fish and prawns in salt pans and mudflats nearby. In recent years, the fruiting of *Manilkara hexandra* is varying to a greater extent. Fruiting is now very low, perhaps suppressed by weather conditions. The population of blackbuck, which was originally around 3000, is declining owing to loss of grassland habitat.

4.3.1 Impact of precipitation change

- Increasing precipitation during monsoon seasons

The projected increase in the rainfall due to climate change in both SW and NE monsoon seasons will have a positive impact on the growth of the TDEF. The surface and subsurface water availability will increase, which will reduce the salinity levels in the soil and water. An increased relative humidity will also encourage flowering and fruiting, enriching and further strengthening the biodiversity of the region as well as increasing the grazing lands available for the wildlife. The increased canopy cover creates nesting places for birds; improved habitat for other wildlife such as Blackbuck, Spotted Deer and Wild Boar. Rainfall during these months also expands the carbon sink potential. However, losses of flowers and young fruits in *Manilkara hexandra* have been noticed due to sudden climatic variations such as droughts or heavy rains. In the absence of such adverse environmental conditions, many fruits may be produced, resulting in a mass fruiting event (Gunarathne & Anoma, 2014)[41]. Eco-tourism will be enhanced due to improved forest health and wildlife. The TDEF in the Point Calimere Ramsar site was found to have a 'medium' vulnerability to the increase in rainfall.

- Decreasing rainfall during summer

During summer, the availability of water for wildlife becomes reduced as most of the ponds are silted and the surface water becomes salinised. Wild animals can starve for lack of water and fodder during this period. The Blackbuck is

[40] Narmada, K., & Annaidasan, K. 2019 Estimation of the temporal change in carbon stock of Muthupet mangroves in Tamil Nadu using remote sensing techniques. Journal of Geography, Environment and Earth Science International, 19(4), 1–7. https://doi.org/10.9734/jgeesi/2019/v19i430096).
[41] Gunarathne, R & Perera, Anoma, 2014. Climatic factors responsible for triggering phenological events in (Roxb.) Dubard., a canopy tree in tropical semi-deciduous forest of Sri Lanka. *Tropical Ecology. 55.*

already competing with the Spotted Deer and feral horses for grazing areas as well as drinking water. The reduction in rainfall during summer will have an impact on the availability of freshwater, induce drought conditions, increase the salinity of the water and the land, lead to proliferation of *Prosopis* in the grassland and increase the vulnerability of herbivores. The grassland and TDEF will tend to degrade due to the lack of water. *Prosopis,* halophytes and other drought-tolerant plants will spread in TDEF areas. Despite those challenges, the scoring found that the vulnerability of TDEF to the decrease in rainfall during summer is low. As for the other results relating to specific climate change parameters, it is necessary to assess the cumulative impacts of many forces, including those arising from climate change and existing pressures on the site.

4.3.2 Impact of temperature change

- Increasing temperature during SW monsoon

The increase in temperature will increase evaporation from the waterbodies such as ponds and small streams, causing effects to ripple throughout the ecosystem to the flora and fauna. The degradation of grasslands creates fodder scarcity for grazing animals. The ecosystem suffers an increasing loss of species diversity, with some sensitive species becoming rarer or locally extinct. The increased temperatures also reduce forest products such as *Manilkara* and *Momordica dioica* (Spiny Gourd). Decreased relative humidity inhibits fruit set. The impacts of the increase in temperature on pollinators may result in poor fruit set and seed set. The vulnerability to the increase in temperature is scored as low, but once again, it is necessary to explore synergies across impacts and cumulative effects when the existing degrading influences at the site are considered.

- Increasing temperature during NE monsoon

The increase in temperature during October–December will not have much effect as the rainfall moderates the impacts. The transpiration of TDEF's canopy will reduce. The sea breeze will also tend to reduce the impacts of a higher temperature at this time.

- Increasing temperature during summer

The increase in temperature in summer increases evaporation, leading to water scarcity. The already meagre water resources for wildlife will become scarcer, and the TDEF ecosystem will show signs of stress. The population of Blackbuck, and other animals are in appreciable numbers, with a potential to increase from sustainable populations under the changing conditions. The degradation of the ecosystem will lead to the spread of drought-tolerant plants such as *Lantana sp*. and *Prosopis.* The photosynthetic efficiency suffers due to increased evapotranspiration. Some of the tree species shed leaves to cope with the water scarcity. The vulnerability of the TDEF to the increase in temperature during summer will be very high.

- Increase of temperature during winter

The increased temperature will further impact the flowering and fruiting productivity in the region. Lesser fruit setting in TDEF due to the increase in temperature will affect the birds as well as the livelihoods of women who are dependent on *Manilkara* fruits.

4.3.3 Impacts of extreme events

- Sea-level rise

The sea-level rise will reduce the sanctuary area due to shoreline erosion on the eastern side. The Olive Ridley Sea Turtles will lose their nesting habitats due to beach erosion. Seawater intrusion in the aquifers and low-lying areas will make the water resources saline and unusable. The species diversity in the TDEF will suffer from these changes. Saltwater flooding will alter the composition of the flora and fauna. More halophyte populations will colonise the site, and many freshwater-loving species will become extinct from the site. The sand dunes along the shore are likely to be eroded. The vulnerability of the TDEF at the Point Calimere Wildlife and Bird Sanctuary to the rise in the sea level will be 'very high'.

- Cyclones

As the TDEF area is located very close to the shore, cyclones will destroy vegetation. Many tall trees will lose canopy, and some will be uprooted. As the area is sandy with extensive sand dunes, there will not be much inundation. However, the plain grasslands will be inundated with saltwater making it more saline and eliminating most grass species. Herbivores will be affected. The recent Gaja cyclone caused extensive damage to the ecosystem, affecting animals such as the Blackbuck, Spotted Deer and birds. About 25 Blackbucks, some Spotted Deer and many birds were killed. In the subsequent years, the number of migratory birds has decreased. Cyclonic storms will increase the rate of shoreline erosion leading to loss of sea turtle nesting habitat. Cyclones also create conditions that favour the spread of aggressive invasive species that disrupt and change the ecosystems of the region. The TDEF in Point Calimere Wildlife and Bird Sanctuary is located very close to the shore, and the cyclone impact will be 'high'.

- Storm surges

Storm surges will cause seawater intrusion and increased salt concentration in the soils around the forest and grasslands. These TDEF ecosystems mostly have saline-sensitive species. Over a period of time, more extensive saltwater flooding and expanded saline areas will inhibit vegetation growth in the sanctuary. Also, storm surges will modify the topography and geomorphology of the area. Fishing, agriculture and aquaculture will suffer from the degraded conditions of the region. The vulnerability of TDEF to storm surges will be 'very high'.

4.4 Mudflats and associated shallow waterbodies

The mudflats and shallow waterbodies in the Panchanathikulam wetland area and an un-surveyed salt swamp have a long history of salt production. Many domestic and industrial salt works operate in the GVS. The salt works have negative impacts on the GVS ecosystem and species composition and affect coastal fisheries in the area. The GVS serves as the spawning and nursing ground for commercially important maritime prawns and fishes, such as *Penaeus indicus, P. monodon, Hilsa ilisha* and *Chanos chanos*. The flow of freshwater from the River Cauvery is now greatly reduced, affecting the biodiversity in and around the GVS. The abundance of many waterbird species has greatly reduced and continues to decline (Tamil Nadu Forest Department Census Records unpublished data). Both species of flamingo – the Greater Flamingo, *Phoenicopterus roseus,* and the Lesser Flamingo, *P. minor* - inhabit the swamp.

4.4.1 Impact of precipitation change

- Increasing precipitation during the SW and NE monsoons

Precipitation in the months from June to September will dilute the salinity levels of the soil and water. The reduction in salinity will increase the productivity of the mudflats since less saline water favours the growth of the phytoplankton, zooplankton and invertebrates on which the bird population relies. However, there is a possibility of increased concentrations of pollutants such as heavy metals, pesticides and agriculture fertilisers, which may have negative impacts on the plankton and invertebrates. About 3.2 million litres per day of effluents generated from the chemical industries, salt industries and tobacco-processing factories is discharged directly into the sea close to the Great Vedaranyam Swamp (Viswanathan et al., 2013)[42].

The increase in rainfall generally favours the migration of birds during October and November. The less saline water enhances the production of the fishery. Catches of crabs, shrimps, and finfish may increase in mesohaline conditions. The salt production will decrease; however, the agricultural productivity will improve significantly. Local bird populations will also thrive because of the plentiful food in the agricultural fields, but higher levels of agricultural chemicals may affect the health of the birds and pollute the ecosystem generally.

The number of Greater Flamingos *(Phoenicopterus ruber)* visiting the Point Calimere wetland has varied in recent years. After the 2018 cyclone, the number of flamingos and other migratory birds reduced sharply but has started increasing again. Migratory birds are visiting the site as the feeding ground has the potential to support a large bird population.

- Decreasing rainfall during summer

During summer, the productivity of the mudflats decreases as the salinity starts rising with the combined decrease in rainfall and increase in temperature. Effluents from salt pans and industrial activity will also increase the salinity, and the pollutants will reduce the availability of feed for the birds. Fish breeding and nursery grounds will suffer. Salt production will improve with the reduction in rainfall and increasing temperature. Larger waders might benefit from increased food in the saline ponds and salt pans. These conditions are also ideal for the proliferation of the saline- and drought-tolerant invasive *Prosopis,* which provides nesting habitats for birds and protects nesting birds against predation. Permanent changes to the ecosystem may occur.

4.4.2 Impact of temperature change

- Increasing temperature during the SW and NE monsoon

The increase in temperature during the monsoon will retard fish and crustacean breeding, which will weaken the food chain for the avifauna. The increased salt production will have ripple effects on the salinisation of the water and soil, which will impact the overall productivity of the mudflats and associated shallow waterbodies.

- Increasing temperature during summer and winter

The increased soil and water salinity in the mudflats will affects their productivity. The increase in salinity reduces the production of the plankton and invertebrates that the birds depend on, constraining bird populations in the PPoint Calimere Wildlife and Bird Sanctuary (Balachandran, 2006)[43]. Already, the population of water birds has been declining sharply in the swamp area due to various ecological pressures (Pandiyan & Asokan, 2016)[44].

The reduction of fish in the swamp will also affect the livelihood of the fishers. They will need to travel further, barefoot, before boarding their boats, increasing the risk of injuries and infections caused by barnacles – already a significant threat. Villagers have observed that, in recent years, barnacles are spreading due to favourable tidal conditions prevailing in greater areas. Earlier, during low tides, the area exposed was relatively small, but now, due to sedimentation, the swamp has become shallow, exposing a greater area to tidal influences. The vulnerability of the swamp to the increase in temperature during summer will be ‘very high’. The increase in temperature in winter will slightly increase the salinity in the mudflats, with a moderate impact on productivity.

[42] Viswanathan S., Usha N. and Anitha P., 2013. Seasonal variability of coastal water quality in Bay of Bengal and Palk Strait, Tamilnadu, southeast coast of India. Brazilian Archives of Biology and Technology. 56. 875-884. 10.1590/S1516-89132013000500020.

[43] Balachandran, S., 2006. The decline in wader populations along the east coast of India with special reference to Point Calimere, south-east India. In: Water birds Around the World. The Stationery Office, Edinburgh, pp. 296–301.

[44] Pandiyan J, Asokan S., 2016. Habitat use pattern of tidal mud and sand flats by shorebirds (Charadriiformes) wintering in southern India. Journal of Coastal Conservation; 20(1): 1–11. Available from: https://dx.doi.org/10.1007/s11852-015-0413-9.

4.4.3 Impact of extreme events

- Sea level rise

The sea-level rise will cause erosion and submergence of the swamp area. This change in the water level may create a place suitable for seagrass beds. There is also the possibility of a loss of bird habitats as the area will be submerged to a greater depth. Fishing will be threatened due to the loss of habitats.

- Cyclones

Cyclones pose a threat to mudflats through erosion, seawater flooding, deposition of marine sediments and topographical changes. Bird feeding grounds will also be affected, with migratory birds affected especially, as observed after the Gaja cyclone in November 2018. Increases in the incidence and severity of cyclones will aggravate the salinisation of the water and soil due to saltwater intrusion.

- Storm surges

Storm surges will create extensive water flooding, affecting burrowing animals such as crabs, mudskippers and eels. Storm surges change the topography and geomorphology, affecting the free flow of water and reducing the overall swamp area. The salinisation of the water and land will further reduce the productivity of the aquatic fauna (finfish and shellfish). The mudflats and associated shallow waterbodies in the Point Calimere Ramsar site have a ‘high’ to ‘very high’ vulnerability to increasing numbers of extreme events.

5 ADAPTATION PLANNING

Point Calimere Wildlife and Bird Sanctuary and the adjacent coastal area have many significant ecosystems such as mangroves, mudflats, estuaries, salt marshes, Tropical Dry Evergreen Forests (TDEF), coral reefs, seagrass beds and lagoons. These ecosystems are highly productive and highly vulnerable to climate change impacts, which can lead to a significant change in species composition and overall biodiversity. The adaptation plan set out in this chapter was developed through multiple stakeholder discussions on the vulnerability issues facing the Point Calimere Ramsar site and on appropriate responses to them. The Adaptation Planning Matrix for each of the target assets developed using the CAM method is attached as complementary material to this report (a list of files shown in Annex 3).

5.1 Mangroves of Muthupet and Thalainayar

The mangroves in Muthupet and Thalainayar are protected by the state Forest Department. The Forest Department has taken adequate measures to protect the wetland from felling and encroachment. The department has implemented large-scale mangrove plantation at these two sites. Yet, the two wetlands were severely affected by the 2018 cyclone and associated storm surge. A 0.5 m sea-level rise will inundate 441 ha and 875 ha of Muthupet and Thalainayar, respectively, causing losses of 4.13% and 18.54% of the forests.

Adaptation Options

Planting of Mangroves

The mangroves might colonise newly elevated areas if *Prosopis* and *Suaeda* are eliminated. The natural colonisation process will need to be supplemented by a comprehensive plantation programme initially with *Avicennia* which can survive changing conditions, followed by other species. A site-specific planting regime should be adopted. Apart from *Avicennia,* other species can be tried, especially as the canopy and density increase. In the periphery, terrestrial species can be planted by tapping freshwater sources.

Drainage canals

Both Muthupet and Thalainayar receive water from the drainage canals. During the monsoon seasons, the freshwater flow is critical to the overall maintenance of the ecosystem health. It will be necessary to introduce a programme of desilting of the drainage canals upstream to bring more freshwater to the site. That would involve other agencies and high-level of commitment within the state.

Participation of local community

The participation of the local fishermen in managing the canals in the past, including clearing debris and monitoring for impediments, helped achieve better tidal water flows. The same traditional method of engagement of this community group should be promoted to achieve win–win outcomes.

5.2 Point Calimere Wildlife and Bird Sanctuary (TDEF Forest)

The Point Calimere Wildlife and Bird Sanctuaryhas Tropical Dry Evergreen Forest (TDEF) and grassland habitats and the endangered Blackbuck. It will be affected by increases in the temperature and the frequency and intensity of extreme events such as cyclones, sea-level rise and storm surges. The extent and quality of the grassland will be reduced due to increasing salinisation. The biodiversity, especially the flora, will be affected by increases in soil and water salinity due to sea-level rises and storm surges. The change in flora composition, especially the loss of grassland species and invasion by exotic species such as *Prosopis,* will reduce the availability of fodder for herbivores. The populations of the Blackbuck and other herbivores will be constrained by the reduction in grazing areas.

The increase in temperature during the SW monsoon (increase by 2.1°C) will have a significant effect on the vegetation of the Tropical Dry Evergreen Forest (TDEF). This increase promotes evaporation in freshwater bodies such as ponds and small streams, with further impact on the dependent fauna and flora. The grasslands used by the herbivores will also be affected. Forest produce such as the fruits of *Manilkara* and Spiny Gourd will be less abundant due to changes in climatic factors. Events such as rise in the sea level, cyclones and storm surges will have far-reaching impacts on TDEF habitats.

Adaptation Options

Restoring freshwater bodies

Desilting of waterbodies such as ponds and streams will be an important adaptation measure so that their capacity to hold freshwater is improved, serving the dependent fauna and flora and reducing saline intrusion. Constructing nature-based water storage structures in elevated areas along the western side of the TDEF using contour bunds to store rainfall, promote infiltration and slow the water flow to the sea will need to be given priority.

Plantation of TDEF plants and fodder grass

A programme for tree planting is required along creeks and around waterbodies to stabilise, protect, minimise evaporation, and provide shelter and fodder for wildlife. The planting regime should include drought-tolerant TDEF plants such as *Manilkara.* Planting and maintaining drought- and saline-tolerant grass species to meet the fodder requirements of herbivores are also needed.

Removal of exotics and weeds

Additional investment in the periodic removal of exotics such as *Lantana sp.* and *Prosopis sp.* and subsequent planting and nurturing of native colonisers will be an important strategy in rehabilitating the ecosystem and increasing resilience.

Controlling shoreline erosion

Hard engineering structures such as physical barriers, sea walls and groynes are options suggested by the stakeholders. Any hard infrastructure intervention must always be accompanied by nature-based measures so that they contribute directly to the net biodiversity gain. Construction of weirs and sluice gates in the drains to prevent the entry of saline water into the wildlife sanctuary could reduce the salinity of the water and soils. Such hard engineering structures need significant financial resources, effective management and ongoing maintenance. This option is least preferred due to its low effectiveness, management costs and potential unwanted impacts. It is given 'medium' priority.

Planting multiple-species shelterbelts

Planting shelterbelts, with dense tree cover, along the sea front to minimise the wind and surge velocities and impacts on habitats further inland will be important, as will shelterbelt restoration after cyclones to aid recovery. Planting sand binders and promoting natural vegetation in the open sand dunes for protection from wind erosion will be needed, including an emphasis on planting native saline- and drought-tolerant TDEF species.

Wildlife rescue and care

Establishing centres for veterinary care, shelter and preparedness for wildlife rescue during and after extreme events will offset the high mortality of and injuries to animals and support the recovery of populations.

5.3 Mudflats and associated shallow waterbodies

The mudflats and associated shallow waterbodies of the Panchanathikulam wetland area and un-surveyed salt swamp area have a long history of salt production. Several domestic and industrial salt works operate in the GVS. The impact of salt works affects the ecosystem, especially the flora and fauna, besides having possible repercussions on coastal fisheries. The flow of freshwater from the river Cauvery is now minimal, so that flows now only come from the immediate catchment. Thus the salinity of the swamp has increased, contributing to changes in the biodiversity in and around the GVS. The swamp serves as the spawning and nursing grounds for commercially important maritime prawns and fishes, such as *Penaeus indicus, P. monodon, Hilsa ilisha* and *Chanos chanos.* The abundance of many waterbird species flocking to the area has declined annually, and these species are now rare. Both species of flamingos, viz., the Greater Flamingo, *Phoenicopterus roseus,* and the Lesser Flamingo, *P. minor,* are found in the Great Vedaranyam Swamp.

The increase in temperature by 2.2°C during the SW monsoon and by 2.1°C during summer will have very significant impacts on the productivity of the fishery resources, which in turn will affect the avifauna. The increase in temperature will be aggravated by the lack of proper tidal and freshwater flushing and affect all the components of the ecosystem, promoting a transformation of the species composition and populations. In addition, extreme events such as rise in the sea level, cyclones and storm surges will have significant impacts on the swamp.

Adaptation Options

- **Desilting the drainage canals**

The canals and the mouth area, including Siruthalaikadu canal, should be desilted for proper flushing. Often, the fishers are not able to use their boats for many days. This activity will need to be conducted regularly – probably annually – but requires close monitoring to determine the rate of sedimentation and the appropriate desilting regime. A challenge is that most of the land is in the revenue area and obtaining permission for desilting may be complex and will require a high level of commitment.

Already, fishers are leaving boats much further inside the swamp and are walking across the mudflats, which exposes them to injuries caused by mollusc shells in the sediments.

Planting shelterbelts

During summer, the area is subject to dust storms. Salt-laden sediments deposit on agricultural lands and settlements, affecting the production, infrastructure and waterbodies. Growing shelterbelts, choosing mixes of native species that the Forest Department have demonstrated success in, along the periphery of the swamp will reduce the salt-laden sediment transported by the winds, provide nesting habitats for the birds and clearly define the site boundary.

Hard engineering structures such as physical barriers, sea walls and groynes are not expected to be effective in controlling extreme events due to climate change. The response should strongly emphasise nature-based solutions. No development of any kind should be undertaken in and around the area that does not lead to net biodiversity gain.

6 SUMMARY OF ON- AND OFF-SITE ADAPTATION MEASURES

6.1 Off-site management and adaptation measures

6.1.1 Ensuring freshwater flows and storage in the wetland

The freshwater flow is minimal and reducing at the Point Calimere Wildlife and Bird Sanctuary, especially the mangroves of Muthupet and Thalainayar, and fundamentally changing the nature of the wetland ecosystem. Those two wetlands are at the tail end of the Cauvery delta. The Thalainayar mangrove wetland receives water from the drainage and enters the Bay of Bengal through the Adappar estuary. Six distributaries of the Cauvery delta discharge their water into Muthupet. However, the freshwater flow has been greatly reduced due to the construction of dams upstream. **To enhance the freshwater flow into the mangroves, the drainage canals and the mouth of the estuaries need to be desilted and kept free of obstructions.**

The existing waterbodies, such as canals and ponds, in the Point Calimere Wildlife and Bird Sanctuary need to be de-silted to increase their freshwater storage capacity. This activity is required for recharging the sub-surface aquifer and to increase the availability of availability for the wildlife. Similarly, establishing new water storage ponds and introducing measures to slow down the runoff in the small watersheds in elevated areas near Ramar Patham should be trialled.

6.1.2 Catchment management

The catchment near the estuary needs to be managed for maximum freshwater flow. Currently, the mangrove wetlands receive water mostly from runoff through drains. These drains need to be desilted through the funds available under the National Rural Employment Guarantee Act 2005 scheme. The Cauvery River flow is greatly diminished, and policy guidelines and a monitoring and enforcement programme should be introduced to ensure a minimum freshwater flow to protect the wetland.

6.1.3 Pollution control

The Point Calimere Wildlife and Bird Sanctuary receives agricultural runoff with large concentrations of pesticides and inorganic nutrients. The farming community needs to be trained in organic agricultural methods and supported in shifting to more sustainable cropping regimes without chemicals. Organic farming systems should be promoted through the Agriculture and Extension Department.

The discharges from salt pans and aquaculture ponds near the Ramsar site significantly increase the soil and water salinity, affecting the flora and fauna and changing the biodiversity. Regulations are needed to reduce and manage these discharges and their impacts. Many stakeholders who were consulted during the adaptation planning sessions felt that there should be limits to the further development of these land and water uses around the Ramsar site.

6.2 On-site management measures

6.2.1 Habitat restoration and management

- Muthupet Mangroves

Large areas of the Muthupet mangroves are degraded and require substantial restoration investment. To date, the success of the mangrove rehabilitation programme has been limited for a combination of reasons, including a reduction in freshwater flows, sandy soils, reduced tidal water flows and siltation of the lagoons and canals.

The restoration of mangroves should be undertaken in areas most suited to mangrove growth, including those areas that will be tidally inundated when the sea level rises. Deeper and wider canals should be dug for tidal water to flow freely. The restoration methods should be monitored very closely, with modifications to the planting and siting techniques according to the topography and changing hydrology of the area. Submergence-tolerant species should be planted in those areas that are likely to be inundated by sea-level rise, such as *Rhizophora*, with its stilt roots. *Avicennia* and *Sonneratia* species with pneumatophores are more likely to survive in the slightly higher areas, although *Sonneratia* is less salt tolerant than *Avicennia,* which will limit its success in hypersaline conditions. A site-specific species plan should be developed as the framework for the restoration activity.

Prosopis and *Suaeda,* the invasive species in the periphery area, need to be removed. The area needs to be replanted with mangroves to increase the forest cover.

Key adaptation measures:

- Restoration of mangroves
- Planting of mangroves, including Rhizophora and Avicennia
- Removal of invasive exotics

- Traditional canal fishing system

The fishers in Muthupet practice traditional canal fishing methods with a system that has been in place for many decades. In this system, the fish entering the canals during high tide are caught using traps as the tide recedes. The fishers usually maintain the canals to ensure that there is a proper tidal flow. There need to be natural mangroves growing along the canals, which will protect the canal banks and provide habitats and food for the incoming fish. This traditional system should be promoted to improve the canal maintenance and mangrove rehabilitation with the active and systematic participation of fishers.

- Thalainayar Mangroves

More than 90% of the mangroves in Thalainayar have been replanted using the canal method. The Forest Department has implemented large-scale plantation between 2010 and 2020. Because the mangroves are short and stunted, they were not affected by the Gaja cyclone (in 2018). Since the freshwater flow is much less, the desilting of drainage canals will improve the freshwater flow in the mangroves.

The proposed adaptation activities include:

- Desilting of the restored canals to maintain the tidal water flow
- Preventing grazing and encroachment

Recently, the government has constructed a check dam and sluice gate to prevent the entry of saltwater from the sea. The dam has stopped tidal water from entering the mangroves, leading to potential changes in the ecosystem. Now more freshwater than tidal water will be flooding the area, bringing additional changes to the ecosystem as mangroves need a tidal water exchange to flourish. However, according to the Forest Department, to date there has not been a great impact due to the dam, and the conditions are being monitored very closely. If changes in the ecosystem due to the dam and a sea-level rise become apparent, the operation of the sluice gate may need to be changed to ensure an adequate tidal exchange for the survival of the mangroves.

In summary, the adaptation measures and principles that are needed are the following:

- Monitoring the impact of the construction of the check dam and modifying the operation of the sluice gates if necessary.
- The monitoring programme needs to be well defined and needs to cover critical ecosystem processes and species.
- No hard structures should be introduced into the site without integrated nature-based measures unless they can lead to net biodiversity gain.

• Point Calimere Sanctuary (TDEF)

Any further spread of *Prosopis* should be prevented and existing areas cleared through strengthened investment and management. Periodic removal of *Prosopis* is required to reduce the impact of the invasion on the native habitats including the TDEF and grasslands. The areas under *Prosopis* should be converted to TDEF, other tree plantations or open grasslands according to a well-planned invasive species control programme. More native species should be propagated and planted in the vacant areas to promote dense cover and shelter for the wildlife.

Restoration planting of TDEF in the Point Calimere Wildlife and Bird Sanctuary will improve the habitat for animals such as the Blackbuck and birds. Species such as Manilkara will provide income to the forest-dependent community. In summary, the adaptation measures that are needed are:

- Restoration of grasslands to enhance fodder availability
- Restoration of waterbodies to ensure the availability of freshwater for the fauna
- TDEF and other trees should be planted along the periphery to provide a habitat for the wildlife and reduce evaporation.
- Construction of earthen embankments on the eastern and south-eastern sides of the sanctuary to avoid saline water intrusion associated with a rise in the sea level and extreme events.
- Plant earthen embankments with suitable trees in a desirable density so that embankments can be strengthened and act as shelterbelts.

• Mudflats and shallow waterbodies in Great Vedaranyam Swamp (GVS)

When consulted, the local fishers and salt producers observed that the tidal flushing had reduced due to siltation of canals. They recommend desilting of the canals including the Siruthalaikadu drain and other drains near Point Calimere. The tidal water flows into the GVS will improve the fish productivity, which in turn supports the avifauna and local fishers. In summary, the adaptation measures that are required are:

- Desilting of mouths and drainage canals
- Planting of TDEF along the periphery to increase the extent nesting habitats available for the birds and to protect the area from cyclones and other natural disasters.

6.2.2 Species support and management

• Mangroves

The mangroves in Muthupet and Thalainayar are predominantly *Avicennia marina.* Diverse mangrove species should be planted to build ecosystem resilience and ensure higher survival levels even if the area is flooded.

- Flamingos

Large numbers of flamingos use the Ramsar site and the neighbouring salt pans as feeding grounds between October and January. Ensuring the continuing biological productivity of the mudflats and shallow waterbodies in the Great Vedaranyam Swamp through the habitat measures described above will be important to maintain the visiting flamingo populations.

Discharge of highly saline wastewater from salt pans and aquaculture ponds will have a negative impact on avifauna and lead to overall ecosystem degradation. Strict measures should be taken to prevent further expansion of these activities in the Ramsar site and to institute effective pollution control measures.

- Blackbuck

The Blackbuck population has increased in recent years due to improved protection. Since one designated function of Point Calimere Wildlife and Bird Sanctuary is to protect the Blackbuck, it is necessary to provide better grazing and water storage facilities to increase their resilience to the ecosystem changes resulting from climate changes and extreme events.

- Nesting area for turtles

Olive Ridley sea turtles use the beach for nesting. The nesting beaches should be well protected from predators such as dogs and jackals. Beach is already vulnerable to sea-level rise and storm surge, and research will be required to develop and implement specific measures to protect the turtle nesting areas such as regular beach nourishment and sand dune protection.

6.2.3 Livelihood support and management

- Mangroves

Traditional canal fishing methods will benefit the canal and mangrove habitats and the community. The community will maintain the canals and participate in mangroves rehabilitation. The improved flow of tidal water and enhanced food content will support fish productivity and income.

- Point Calimere Sanctuary and Great Vedaranyam Swamp

Planting *Manilkara* and Spiny gourd in the TDEF will bring ecosystem benefits and provide income for the forest-dependent community. Desilting of drainage canals and planting of mangroves will increase fish populations and improve the income of small-scale traditional fishers.

6.2.4 Addressing sea level rise

- Mangroves

Planting of mangroves will reduce the impact of the rise in the sea level as the root system tends to accumulate soil and stabilise it. Planting *Rhizophora* in those lower lying areas that are likely to be inundated (*Rhizophora* will survive better when inundated as it has longer aerial stilt roots compared with *Avicennia*).

- Point Calimere Sanctuary and Great Vedaranyam swamp

Planting dense TDEF along the periphery of the sanctuary and desilting drainage canals will reduce the impact of the rise in the sea level rise.

6.2.4 Protection against extreme events

- Mangroves

Mangroves are the first line of defence against extreme events such as cyclones, the rise in the sea level and storm surges. Planting mixed-species mangroves in the degraded areas, including *Avicennia marina* and *Rhizophora,* will create more resilient forests, providing better protection compared with planting only *Avicennia marina. Sonneratia* may also be planted in those areas not exposed to hypersaline conditions.

- Point Calimere Sanctuary

Planting dense TDEF will provide better protection from extreme events. Conservation and management of sand dunes are also very important.

6.3 Point Calimere monitoring programme

6.3.1 Survey

Regular surveys are needed to collect data on the biological, chemical, and physical features of Point Calimere Wildlife and Bird Sanctuary, its habitats and its species that reflect the ecological condition of the wetland or key indicators of stress that may influence its health and resilience. Data for each of these indicator groups are to be obtained from field observations, field samples collected at the wetland site and laboratory analyses of field samples.

6.3.2 Research

There has been a useful research programme on the Point Calimere Wildlife and Bird Sanctuary that can provide valuable scientific information for the design of adaptation measures. This programme needs to be continued to fill gaps in the knowledge and understanding of the wetland ecology, its responses to climate change pressures, and requirements of endangered and threatened species and their habitats.

6.3.3 Monitoring

A comprehensive monitoring programme is required at Point Calimere Wildlife and Bird Sanctuaryand for monitoring the freshwater sources in its immediate catchment. Already the flow of freshwater from the wider Cauvery River basin has virtually stopped, and without efforts to make use of rainwater that falls locally, the wetland will be fundamentally transformed in the decades to come, with losses of biodiversity, scientific, cultural, tourism and livelihood values.

A consistent, thorough and timely wetland monitoring, and assessment programme is a critical tool for Ramsar site managers for managing and protecting the wetland resources better. An effective monitoring programme allows managers to establish a baseline for the wetland’s extent, condition and functions; to detect changes; and to characterise trends over time.

Research, survey and monitoring are fundamental to the detailed design of adaptation measures and their effective implementation and the overall adaptive management of the Ramsar site. As a first step, there is a need to fill some of the information gaps about the site. The structure of the monitoring programme should include:

- Long-term measurement of climate parameters, including local air temperatures, maxima and minima, rainfall, humidity and wind speed and direction and measurement of extreme events
- Monitoring of the hydrology and water quality of the local catchment, and efforts for conservation of freshwater, e.g., establishment of ponds and groundwater storage. The discharge of highly saline water from the salt pans should be closely monitored as should the salinity of the groundwater.

- Monitoring the habitat conditions within the Ramsar site, including:
  - Water quality in the creeks and lagoons, with a focus on temperature, salinity, dissolved oxygen, suspended solids and turbidity and nutrients and phytoplankton dynamics. Routine monitoring sites should be established so that time series of water quality changes can be built up.
  - Condition of the mangrove forests in both Muthupet and Thalainayar RF, focussed on mature trees and the survival of more recent plantations and the condition of blank areas where mangroves have been lost and where new plantations could be planned. Monitoring should include the species composition of the mangroves, size and health of the trees, and any larger changes in the plots, e.g., loss of or damage to trees from cyclones and storm surges.
  - Condition of the Tropical Dry Ever Green Forests (TDEF) and grasslands in the Point Calimere Wildlife and Bird Sanctuary, considering the changes in species composition and size and health of the forest trees, especially *Manilkara hexandra.* The invasion of the grasslands by *Prosopis juliflora* should be monitored carefully to prevent further spreading.
  - The condition of the beaches and sand dunes should be monitored, focussing upon the extent to which sea level rise, cyclones and storm surges are causing erosion or loss of integrity.
  - The condition of the mudflats and shallow waterbodies in the Great Vedaranyam Swamp (GVS) should be monitored, focussing upon the quality of the water in the lagoon and groundwater, along with changes in the salinity, the nutrients and the productivity of the phytoplankton and zooplankton, as well as the fish and crustaceans.
- Monitoring keystone species populations, including the populations of the Blackbuck, Olive Ridley sea turtles and migratory and resident birds, such as flamingos, fish and crustaceans, in the creeks and inundated mangrove areas. Census of key species should be carried out routinely every year.
  - The continued growth of Blackbuck population should be monitored, but within the limits of sustainability of the grasslands and forests. Attempts should be made to understand the population dynamics in relation to climate change.
  - The nesting of Olive Ridley sea turtlesshould be monitored each year, and the correlation between climate events and the conditions of the nesting beaches should be investigated. Linkages with research at Bhitarkanika on the optimum nesting conditions of the beaches may be used for comparison with the conditions of the beaches at Point Calimere Wildlife and Bird Sanctuary.
  - Regular bird census should be carried out every year and the numbers correlated with any observed changes in the habitat conditions and food sources at the Ramsar site.
  - For the fish and crustaceans that are dependent upon the mangroves, lagoons and swamp areas for spawning and nursery areas, routine monitoring of the adults and juveniles should be carried out at an appropriate time of the year.
- Monitoring of tourism numbers, survey of tourism facilities and visitor experiences will help improve the designs of the facilities and activities at Point Calimere Wildlife and Bird Sanctuary. The impacts of tourism on the conditions at the Ramsar site, including encroachment, effluents and water pollution, solid waste disposal, and disturbance of wildlife, should be monitored. The extent of damage to facilities caused by cyclones and other climate events should also be monitored.
- Monitoring the effectiveness of adaptation measures. For each measure implemented, indicators of the changes or impacts that the adaptation measure is designed to address, should be developed and monitored at least once a year

This programme of research, survey and monitoring will allow a targeted design and adjustment of adaptation measures by identifying areas and habitats where a measure can be implemented and then keeping track of its effectiveness.

Once put in place, monitoring can show if the impact of negative influences and changes are reduced, if keystone species populations are recovering and thriving, if habitats are healthy and the water quality is good. Alternatively, monitoring will show if there is a continued decline in conditions or numbers. In that case, the adaptation measures may require adjustment or may need to be supplemented by other approaches.

6.4 Stakeholder engagement

6.4.1 Stakeholder roles in adaptation planning

The roles of the different stakeholders in the planning and implementation of adaptation activities are summarised in Table 10.

Table 10 *Stakeholders to be involved in adaptation planning at Point Calimere Wildlife and Bird Sanctuary*

Stakeholder	Rights, roles and responsibilities for the ramsar wetland site	Role in adaptation planning
Tamil Nadu State Wetland Authority	Managing the wetland; coordinating the different agencies at the Ramsar site; preparing projects for the development of the Ramsar site	• Coordination of adaptation planning and implementation; provision of a platform for consultation and planning, mediation and conflict resolution.
DFO (Wildlife Warden - Nagapattnam) Tamil Nadu State Forest Department	Managing the Point Calimere Wildlife and Bird Sanctuary and Thalainayar RF; implementing projects/schemes/protection/wildlife censuses; eco-tourism	• Mangrove replanting and research. In Thalainayar, the construction of check dams in Adappar estuary is one of the concerns affecting the free flow of tidal water for the mangroves. • TDEF replanting and invasive species control. Beach and sand dune protection. Grassland and Blackbuck protection. Monitoring surveys and research into climate change impacts and adaptation • Coordinating the participation of the local community to ensure better protection in TDEF and providing eco-tourism livelihood opportunities for the local community
Joint Director and Deputy Director, Fisheries, Nagapattinam	Implementing fishery schemes Implementing fishery acts and regulations	• Protection of fish habitats and fishing techniques Management of aquaculture development and improvement of aquaculture practices that do not damage the wetland
DFO (Thiruvarur), Tamil Nadu State Forest Department	Conservation and management of Muthupet mangroves - mangrove restoration; eco-tourism	• Mangrove replanting and research, and invasive species control • De-silting of creeks and planting of riparian mangroves • Monitoring surveys and research into climate change impacts and adaptation
Assistant Director, Fisheries, Thiruvarur	Implementing fishery schemes Implementing fishery acts and regulations	• Protection of fish habitats and fishing techniques • Management of aquaculture development and improvement of aquaculture practices that do not damage the wetland
Small salt producers	Salt production near the Ramsar site	• Improved salt production techniques with reduced discharges of highly saline water into the swamp and creeks
Farming families in Kadinelvayal	Farming activity near the Ramsar site	• Reduced use of agricultural chemicals that run off into the Ramsar site

Stakeholder	Rights, roles and responsibilities for the ramsar wetland site	Role in adaptation planning
Fishing/salt-producing families in Kovilthavu	Fishing in Great Vedaranyam Swamp salt production near Great Vedaranyam Swamp	• De-silting of creeks to ensure improved tidal exchange • Improved salt production techniques with reduced discharges of highly saline water into the swamp and creeks
Fishing families in T Maravakadu	Fishing in Muthupet mangroves; restoring mangrove forest (with MSSRF and Forest Department)	• De-silting of creeks and planting of riparian mangroves to ensure improved tidal exchange and access for fishers • Mangrove plantation and restoration
Fishing/labour for salt producers/	Fishing in marine water (shallow); Great Vedaranyam Swamp Labour work in salt pans	• De-silting of creeks to ensure improved tidal exchange
TDEF non-timber forest produce -collecting families in Kodiakadu	Collection of NTFP in Point Calimere Wildlife and Bird Sanctuary	• Improved salt production techniques with reduced discharges of highly saline water into the swamp and creeks • Re-planting of TDEF areas and beach protection measures
BNHS	Studies related to avifauna	• Surveys and bird census. Research into flamingo feeding requirements and habitat improvement/ protection
DHAN	Studies related to socio-economic assessment in Point Calimere Wildlife and Bird Sanctuary	• Community involvement and livelihood benefits of adaptation measures • In the TDEF management the participation of the local community will ensure better protection. • Through eco-tourism, the local community will benefit from additional income.

6.4.2 Recommendations for improving stakeholder engagement in planning

The Tamil Nadu State Wetland Authority needs to establish a coordination platform for the planning and implementation of the adaptation measures involving relevant stakeholders. The Forest Department responsible for different areas should incorporate the appropriate measures within their existing management plans and budgets for the Ramsar site, including obtaining NREGA funding. The Fisheries Department will need to be involved in consultations with the fishing and aquaculture communities and in fish habitat protection. Other government departments should be closely involved in implementing the adaptation plan, such as Revenue Department which owns land in the Great Vedaranyam Swamp and the Tourism Department which has interests in the tourist attractions of the Point Calimere Wildlife and Bird Sanctuary. Coordination of activities in the Great Vedaranyam Swamp (GVS) is likely to be complex because there are many owners and stakeholders using this area. Village-level institutions should be formed to allow their greater involvement in the planning and implementation of the adaptation measures.

The adaptation measures to be implemented need to be underpinned by research and development and their effectiveness monitored through regular surveys and census, combining changes in climate and adaptation impact. In this way, adaptation can be incorporated into the adaptive management of the site. Research should be coordinated by the Wetland Authority and Forest Department with promotion and facilitation of participation by NGOs and academic institutions.

7 CONCLUSION

This report provides an assessment of the vulnerability of the Point Calimere Wildlife and Bird Sanctuary and its key assets to the projected climate change including increased rainfall in the monsoon periods, and decreased rainfall in the dry season, coupled with a general increase in temperature throughout the year. The assessments show that these changes in seasonal climates will be exacerbated by increased frequency and intensity of extreme events of sea-level rise, cyclones and storm surge.

The Point Calimere Wildlife and Bird Sanctuary falls naturally into three distinct habitat types, the mangrove and creek areas of Muthupet and Thalainayar, the Point Calimere Sanctuary, with its Tropical Dry Evergreen Forest, grasslands and sandy beaches, and the Great Vedaranyam Swamp, with its creeks, mudflats and associated salt pans. The vulnerabilities of these three habitat types, representing the main target assets of the site, have been assessed and adaptation measures proposed.

The key issues affecting the site include the increasing salinity of the enclosed waters in the creeks with reduced tidal exchange and a shortage of freshwater entering the site from the Cauvery River. The creeks are becoming heavily silted, which further reduces the tidal exchange and the productivity of the mangrove and mudflat areas on which the fishery and wildlife depends. The mangroves are becoming degraded with gaps created by cyclones, and invasion of higher-lying areas by exotics such as *Prosopis* and *Suaeda.* Cyclones have also created gaps in the TDEF of the sanctuary area, which is also suffering from a shortage of freshwater, and invasion of the degraded forested and grassland areas by *Prosopis.* In the Great Vedaranyam Swamp (GVS), the increasing salinity of the creeks and land area and silting-up of creeks are exacerbated by the release of highly saline waters from the salt pans that surround the swamp and the release of polluting water from the aquaculture ponds.

All those issues and trends are likely to be exacerbated by climate change. The sea-level rise will inundate some of the mangrove areas permanently, leading to a dieback of the mangroves while exposing some slightly higher areas to tidal inundation, making them suitable for mangrove reforestation. The sea level rise, cyclones and storm surges are likely to lead to erosion of the beaches and sand dunes where the Olive Ridley sea turtles nest. The livelihood interests of the villagers living around the Ramsar site include small-scale fishing in the creeks and open water in the swamp, collection of NTFPs from the mangroves and TDEF, and tourism activities, especially in the sanctuary area. All these will be affected by the degradation of the habitat induced by climate change.

A range of adaptation measures are presented as options for dealing with these issues, some of which are already included in current management plans as necessary responses to existing pressures. This climate change assessment serves to reinforce the need for these management measures to be carried out with due care and attention, e.g., mangrove replanting and gap filling in the TDEF, and desilting of the creeks to ensure tidal exchange. The storage of freshwater from the monsoon rainfall to replace the loss of freshwater flows from the Cauvery River, which now scarcely reaches this part of its delta, will be an important contribution in combating increasing salinity. Beach and sand dune protection will be necessary for protecting the sanctuary area against the sea-level rise and storm surges, and for protecting suitable nesting sites for the turtles. The control and management of highly saline discharges from the salt pans and polluting runoff from the surrounding agricultural fields will be essential for maintaining productive water conditions for fisheries and feeding waterfowl, especially the flamingos.

The implementation of these adaptation and good management measures will need the coordination and cooperation of the different stakeholders involved in and using the Point Calimere Ramsar site. The management of the site is complex, with different land ownership and management responsibilities divided between the Forest Department, Fisheries Department, Revenue Department and Tourism Department, coupled with the livelihood interests of the salt pan, agriculture and fishing communities. A climate change adaptation coordination platform under the State Wetland Authority is needed to agree on the measures that should be implemented over the next decade to protect the site against the existing degrading influences and the increasing influences of climate change. Adaptation measures need to be developed and planned on the basis of appropriate research, surveying and monitoring of effectiveness to guide adaptation and ongoing innovations.

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9 ANNEXES

9.1 Annex 1 – The Climate Change Vulnerability Assessment and Adaptation Planning Methodology

9.1.1 Impact and vulnerability assessment

The starting point for the CAM method is the characterisation of the projected climate changes or threats and opportunities. The CAM method considers resilience as integral to ecological sustainability. Both concepts are linked by the motivation to establish a long-term perspective in which change and adjustment are intrinsic to effective wetland conservation and management. Achieving this long-term perspective requires an approach to threat analysis that involves understanding past trends and experiences, as well as projections and quantification of the range of future conditions. The CAM approach integrates the needed long-term perspective into the assessment by quantifying the past and future hydro-climatic conditions for the Ramsar sites and landscapes surrounding them as the basis for characterising climate change threats and as the foundation of the vulnerability and adaptation assessments and planning.

The climate change impact and vulnerability assessment follows a recognised pattern of assessing the exposure and sensitivities to the climate change threats and the likely impacts that may result. When combined with the adaptive capacity of the target asset or system, a ranking and analysis of their vulnerability can be made. The operational climate change impact and vulnerability assessment process involves six main steps as shown in Figure 18.

ASSETS Identifying the assets	THREATS Defining the climate change threats and opportunities	BASELINE ASSESSMENT	IMPACT ASSESSMENT Exposure Sensitivity	ADAPTATION CAPACITY	VULNERABILITY Impact/ Adaptation Capacity
Defining the asset inventory the main existing and planned infrastructure assets/systems in the area	Expressing clmate change conditions in terms relevant to the assets and target area covering threats and opportunities	Documenting past and existing conditions including climate variability and extreme events	Assessing the potential impacts of the threats and opportunities on the assets and area	Assessing the capacity of the management agencies and communities to respond and recover from the impacts	Establishing the relative level of vulnerability based on the impact and adaptive capacity

Figure 18 *Climate change impact and vulnerability assessment steps*

9.1.2 Determination of the scope and target assets

The first step in the planning process was to set the boundaries or scope of what is being assessed. The scope described the limits of the planning task, including the time horizon, geographical area, sectors or assets to be covered, and resource availability for the assessment (e.g., money and human resources).

For this assignment, the Ramsar sites themselves set the primary geographic boundaries of the assessments, although it was necessary to consider the impacts of climate change within the wider context of the sites, in particular, the hydrology in the upstream catchment and the dependence of the downstream areas on water flowing through the Ramsar site (see Figure 19 to Figure 22).

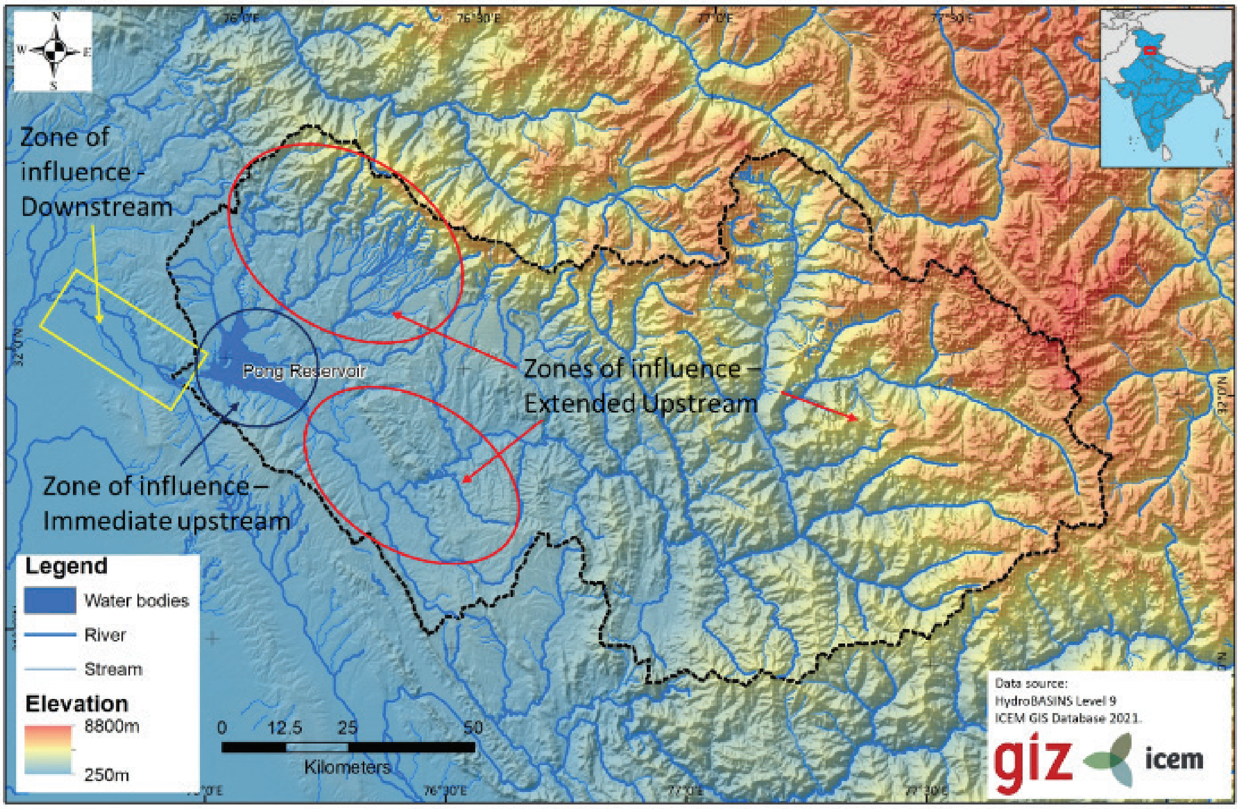

Figure 19 *Pong Dam lake and zones of influence within its catchment*

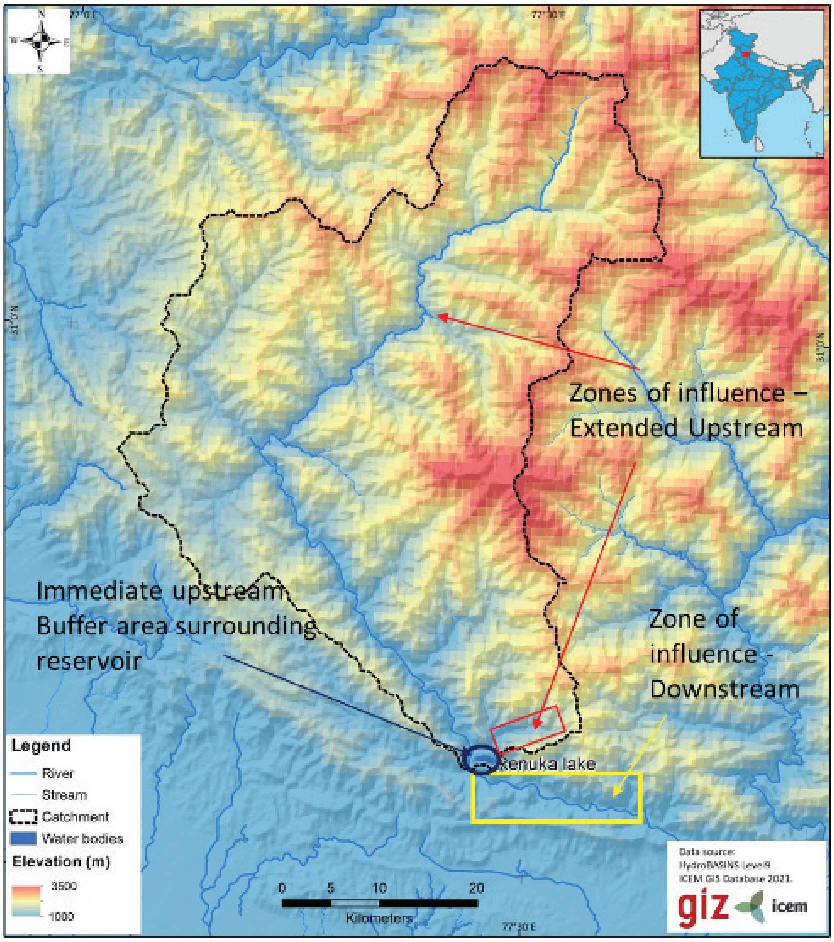

Figure 20 *Renuka wetland and zones of influence within its catchment*

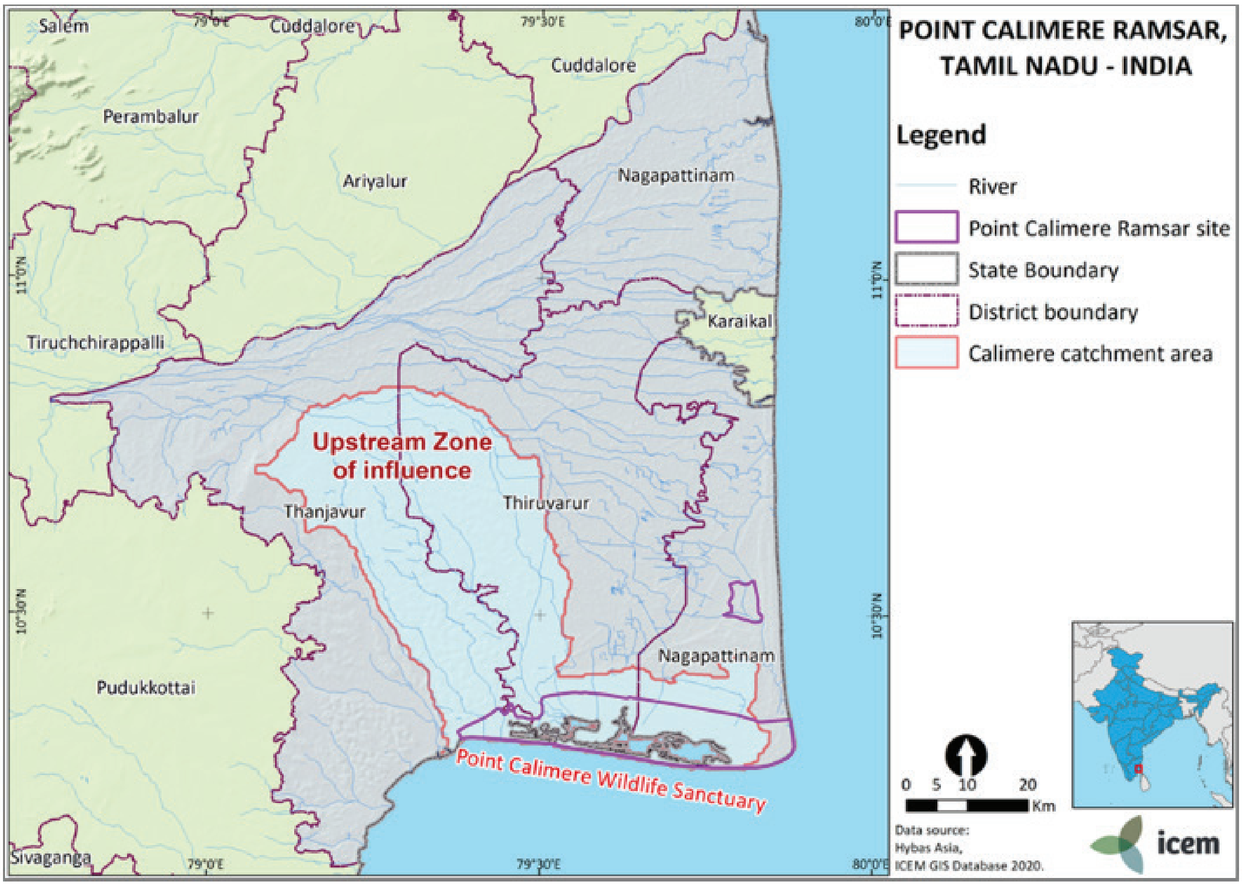

Figure 21 Point Calimere Wildlife and Bird Sanctuary and its upstream zone of influence

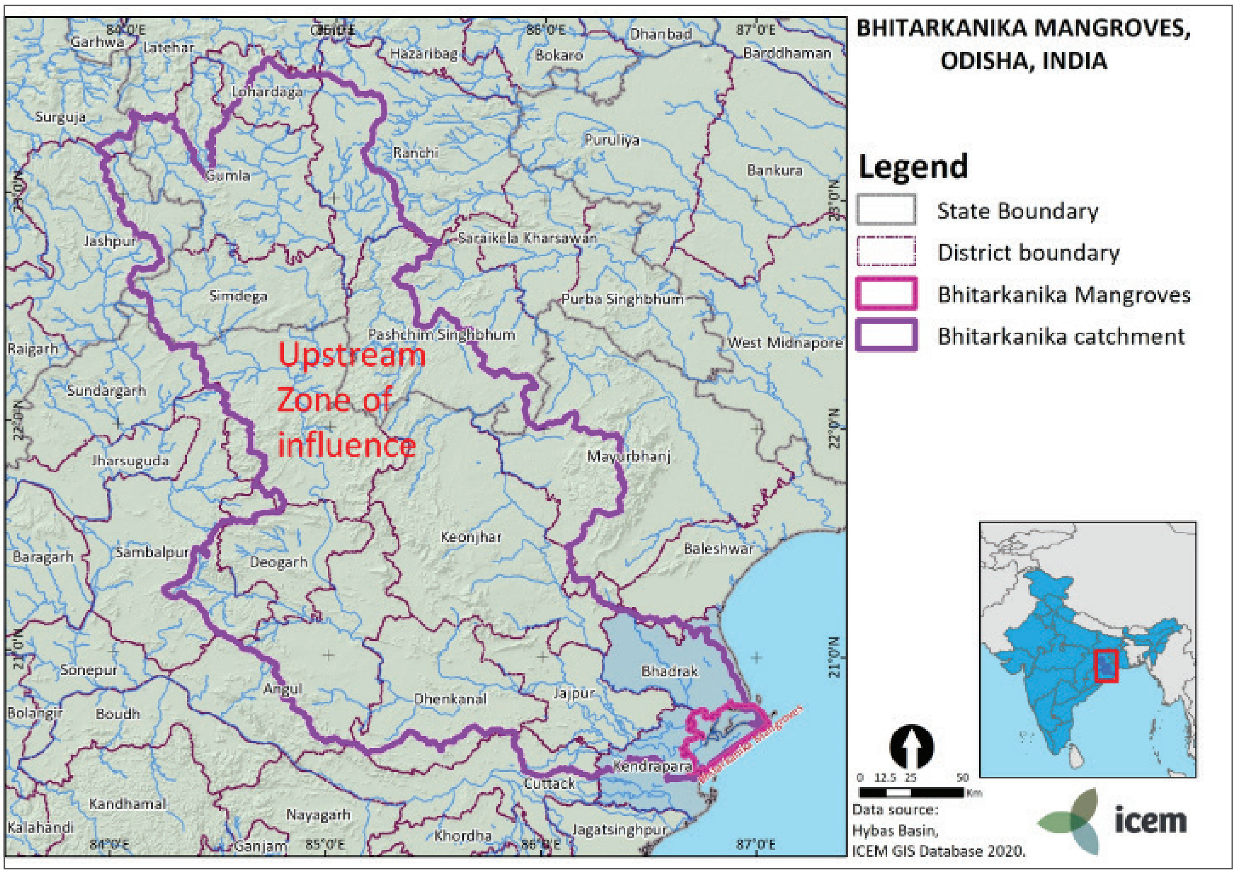

Figure 22 Bhitarkanika mangroves site and its upstream zone of influence

In terms of a time horizon, we considered trends from the past 20 to 30 years and the impacts of climate change to 2050. This forward time slice is sufficiently in advance for climate changes to have become evident and yet short enough for the planning of realistic adaptation measures. Existing climate change models have used this time horizon.

The primary sectors involved were the natural ecosystems and their services and uses associated with each Ramsar site. Where appropriate, it was necessary to consider the influence of water infrastructures such as the multi-purpose Pong Dam or water control and erosion structures.

The wetland 'assets' were the target for the vulnerability assessment, and depending on whether the target was infrastructure, a natural system or a settlement, for example, the assets might include:

- The main natural components – e.g., species, habitats and other geographic features
- The services provided (including ecosystems services such as tourism)
- The communities served and nature of services – (including key NTFPs)
- Settlements and infrastructure
- The main infrastructure components – for e.g., an irrigation system might include the water source and catchment, sediment trap, pumps, canals, culverts, distribution pipes and command area
- The main components of the area or settlement, such as agricultural fields, schools and markets.

The assessment did not include primary surveys of the natural assets. Data were derived from previous investigations, reports and management plans as well as stakeholder input. The resources available allowed the Ramsar sites to be visited by the team for detailed discussions and observations to facilitate the assessments and to build the capacity of the Ramsar site managers and stakeholders.

• Target asset selection

We recognised that it was not possible to conduct a vulnerability assessment of all of the natural, ecosystem service and infrastructure assets present at each Ramsar site because the level of detail required for each assessment would become unmanageable. Each Ramsar site as an entity was assessed together with some carefully selected assets that reflect its essence. Which assets to choose come out of the baseline description of the wetlands, which was developed during the field missions.

It is necessary to establish the primary purpose of the system being investigated and how each component contributes to that purpose. For e.g., a mangrove swamp might function to protect against cyclones and provide livelihoods for local communities (e.g., from fishing and ecotourism), or a small irrigation system might have the objective of delivering about 0.9 litres/s/ha of water to a command area of 300 ha. Defining the purpose of the system/assets assists in assessing the impacts of climate change and helps define adaptation options that assist the system/asset in continuing to achieve its objectives with climate change.

The individual assets fall within the following categories:

- **Physical infrastructure** that determines the wetland character - we do not select the hydrology or chemical characteristics, e.g., salinity profile, of the wetland because these are likely to change with the climate and directly impact the habitats and species (i.e., they become part of the threat). However, we may choose infrastructure that regulates flows and water levels in the wetland or shoreline protection infrastructure as appropriate.
- **Key habitats** that define the wetland ecosystem - we would select the predominant habitats within the wetland.
- **Keystone species** for those habitats, without which the habitat would change or which are essential for the maintenance of ecological processes, e.g., the main plant species within the habitat, food web species, breeding species and top carnivores.

- **Important wetland species for Ramsar site definition,** which are the justification for international designation and conservation and protection areas. These may not be keystone species but may already be under threat and are often flagship or iconic species.
- **Ecosystem services** important for local people using the Ramsar site. These may relate to provisioning services such as fishing, livestock husbandry, agriculture or salt production or cultural services such as festivals, recreation and tourism.

The process of selecting assets for assessment was consultative – obtaining opinions on important habitats, species and ecosystem services from stakeholders during the baseline field mission. A shortlist of assets (habitats, species, ecosystem services and infrastructure) was developed for each site, and then a simple scoring system based upon professional judgement was applied using the following criteria:

- **Representativeness:** the assets should be broadly representative of the ecological processes, habitats and species found in the wetland.
- **Ecological significance:** the assets should be closely linked to ecological processes that characterise the wetland.
- **Importance for the Ramsar site:** at least one of the assets should be linked to the criteria for the designation of the Ramsar site.
- **Sensitivity to environmental change:** the asset should be known to be sensitive to changes at the wetland site, e.g., from past experience, have populations varied from year to year depending upon environmental conditions?
- **Threats:** the asset should be already under threats from non-climate factors and be the subject of particular management/protection measures.
- **Availability of information:** there should be sufficient data, e.g., about populations and distributions within the wetlands to be able to semi-quantify likely impacts.

One or two assets from each type were chosen, considering the ones that score highly on the criteria as shown in the scoring sheet (Table 11).

Table 11 *Scoring sheet to aid target asset selection*

Criterion	Question	Asset 1	Asset 2	Asset 3
Representatives	To what extent is the habitat, species or ecosystem service representative of the site?			
Ecological significance	To what extent is the habitat, species or ecosystem service significant to the ecological processes?			
Ramsar importance	To what extent is the habitat or species important for threatened or designated species?			
Sensitivity to change	To what extent has the habitat area/condition, species numbers or productivity of ecosystem service varied over the past 20 years as conditions change ?			
Non-climate threats	To what extent is the asset threatened by non-climate challenges, or is the focus for management ?			
Availability of data	To what extent is data available on the habitat area/condition, species populations, or ecosystem service(for the site or region)?			
Total	**Sum the scores for each asset**			

9.1.3 Conducting the baseline assessment

The baseline assessment describes the past and existing situations, trends and drivers affecting the target system/asset. It involves documenting climate and hydrological change projections that will affect the system/asset and surrounding area and compiling a climate change opportunities and threat profile. Usually, the process requires field missions to relevant locations and consultation with stakeholders, including local government officers, site managers and affected communities. The main components of the baseline description include (Figure 23):

- Status and trends of natural systems
- Asset inventory and priority setting
- Socio-economic and trend assessment
- Past climate variability and extreme events
- Climate change threat and opportunities profile
- Adaptation audit of past protection measures

Figure 23 Components of the baseline assessment

For this assessment, the description of the past and existing situations and conditions at the four Ramsar sites were derived from existing information, the literature, surveys and reports.

The main references include:

- Ramsar Site Information sheets, which describe the sites and the criteria used for designation
- Subsequent surveys and monitoring of the flora and fauna at the sites, e.g., as carried out using the Wetland Inventory, Assessment and Monitoring System (WIAMS)
- The hydro-ecological assessments were carried out for all the four Ramsar sites.
- The management plans that are available for the Ramsar sites or the forest areas around them.

This information was supplemented by the field missions to each site and discussions which were had with the Ramsar site managers, Rangers and other stakeholders and user groups.

The baseline assessment report for each site (Chapter 2) contained:

- A description of the key wetland ecosystem functions and habitats
- A species/systems database, including climate tolerances
- Descriptions of impacts of past extreme events (including results of participatory flood mapping with stakeholders)
- Identification of the existing threats and pressures acting on each of the wetlands
- Ecosystem profiles covering key habitats and ecosystem services
- Analyses of existing institutional and management arrangements and measures for each wetland site

9.1.4 Determination of climate change threats

The assessment of climate change threats was conducted using a consistent framework involving two key aspects: (1) analysing and documenting past extreme events and trends; (2) developing climate change and hydrology projections against various scenarios (Figure 24).

Figure 24 *Key elements in the climate threat assessment*

A participatory method was used for threat assessment where modelling was not feasible, or government data were not available. This method was used in combination with GIS digitising techniques with support from experts and communities.

9.1.4.1 Past extreme events and trends

Past extreme events, which include floods, storms, landslides and droughts, are important for characterising climate threats. They were investigated and documented for an appropriate time interval, e.g., 20–30 years' history of temperature, rainfall and extreme events. The geographic area was also an important consideration for examining historical extreme events. It was necessary to conduct the assessment beyond the primary boundary of each Ramsar site, including the upstream and downstream zones of influence (Figure 19 to Figure 22).

Using the latest downscaled climate models and scenarios, projections and maps were developed for the seasonal temperature and rainfall changes, hydrological change and likelihood and intensity of climate events in each catchment of each site. For the coastal wetlands, the sea-level rise and storm surges are critical, affecting the mangrove sustainability at the sites, and so the patterns and strengths of these extreme events were also investigated. These were aligned with earlier projections at the state/regional level.

A comprehensive understanding of climate change projections at the Ramsar sites has profound importance for risk assessments, adaptation planning and other decision-making processes.

ICEM first attempted to consider all the available assessments covering the four Ramsar sites that had been recently conducted by the Government and GIZ's consultants, including:

- Hydrological modelling reports for each of the Ramsar sites[45 - 48]
- National assessments conducted in 2020 by the Ministry of Earth Sciences (MoES)[49] and in 2010 by the Indian Network on Climate Change Assessment (INCCA)[50].

- ## Hydrological modelling reports

The hydrological report for Pong Dam Reservoir is a final report, recently developed by a GIZ consultant. It provides a detailed climate change assessment for the whole Pong basin that used the Coordinated Regional Climate Downscaling Experiment South Asia (CORDEX - SA) with RCP 4.5 and RCP 8.5 scenarios. The ensemble mean of three regional climate models (RCM), namely, REMO (from MPI), RCA4 (from SMHI) and CCAM (from CSIRO), was used for the analysis. The report provides valuable projections of changes in precipitation (in %), and maximum

[45] INRM Consultants Pvt Ltd, 2021. Modeling Climate & Hydrological Risks Associated with Ecosystem Functioning of Pong Reservoir, Himachal Pradesh. Final report (draft). Prepared for GIZ. New Delhi, India.
[46] ACWADAM and PSI, 2020. Renuka Wetland Hydrogeological Assessment, Management Strategies and Capacity Building. Interim Report. Prepared for GIZ.
[47] Institute of Technology and Sciences, 2020. Hydro-ecological assessment for integrated management of Point Calimere Ramsar site. Interim Report. Prepared for GIZ.
[48] Chilika Development Authority, 2020. Hydro-ecological assessment for integrated management of Bhitarkanika Ramsar site, Odisha. Interim Report. Prepared for GIZ.
[49] Krishnan, R., Sanjay, J., Gnanaseelan, C., Mujumdar, M., Kulkarni, A. and Chakraborty, S., 2020. Assessment of Climate Change over the Indian Region: A Report of the Ministry of Earth Sciences (MoES), Government of India (p. 226). Published by Springer Nature.
[50] Indian Network on Climate Change Assessment (INCCA), 2010. Climate Change and India: A 4X4 Assessment A sectoral and regional analysis for 2030s. Published by Ministry of Environment & Forests.

and minimum temperatures (in °C) across the Pong basin for 2021–2050 and 2071–2100, with respect to a baseline period of 1981–2010. Unfortunately, it does not contain actual figures of precipitation (i.e., in mm) and temperature (in °C) for the baseline as well as future projections, which are important to the vulnerability assessment process.

Such detailed assessments are not available for the other Ramsar sites. The hydrological reports provided for Renuka wetland, the Bhitarkanika mangroves and Point Calimere are interim reports. They contain some useful information on hydrological assessment but no or very little information on climate change for these sites.

In addition, it is likely that the climate change assessments of the Ramsar sites were conducted using different approaches. In particular, the projections for Pong Dam lake were based on an ensemble mean of three regional climate models, including REMO, RCA4 and CCAM. In contrast, the projections for Bhitarkanika, as described in the interim hydrological report, were based on an ensemble of three other climate models, including HadGEM2, GFDL, and MIROC (conducted by Central Water Commission (CWC) in 2015).

- National assessments

The most recent national assessment was reported in 2020 by the Ministry of Earth Sciences (MoES). It indicated future projections of the precipitation, temperature, sea level and some other parameters across the Indian region for the near future (2040-2069) and far future (2070-2099) with respect to a baseline period of 1976–2005. This assessment is mainly based on peer-reviewed scientific publications, analyses of long-term observed climate records, paleoclimate reconstructions, reanalysis datasets and climate model projections from the Coupled Model Intercomparison Project (CMIP) the CORDEX and the NASA Earth Exchange (NEX) data.

Another national climate change assessment for the 2030s, with respect to a baseline period of 1961-1990, was conducted in 2010 by Indian Network on Climate Change Assessment (INCCA), as part of the National Action Plan on Climate Change (NAPCC). Indian states then developed their own State Action Plan on Climate Change by adapting projection results from this national assessment.

Though these assessments provide comprehensive projections of climate change across India, it is difficult to extract sufficient detail for site-based investigations. In particular, they have a very broad geographic coverage, from regional to national levels. These assessments generally provide climate projections at the annual scale, seasonal projections normally being omitted. In addition, the 2020 assessment tended to compare different climate change datasets/models and reported changes using wide-range figures (e.g., precipitation in the Himalaya will increase 20-40%) that would not be suitable for a specific site-based assessment.

- ICEM's site-based assessment method

Currently available assessments (i.e., from hydrological reports and national assessments) provide valuable references for this project, but they are insufficient for site-based assessments. Using different data sources for each site would cause incorrect interpretations and thus inappropriate vulnerability assessments and adaptation measures. Consequently, ICEM suggests that a consistent climate change assessment approach (in terms of modelling, datasets and time durations) should be adopted for climate change projections at the four Ramsar sites.

With the introduction of Coupled Model Intercomparison Project 5 (CMIP5) Global Climate Models (GCMs) as a part of the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report, new GCM data with significant improvements in climate simulations are now available. It is challenging to select appropriate climate models for the area of interest from a pool of approximately 100 GCMs and four RCPs. The selection criteria could vary depending on the objective of the study and the subjects chosen. The selection process also depends on different data sources, which have different spatial and temporal resolutions. For this assignment, ICEM investigated CMIP5 GCMs data provided by WorldClim with the RCP 8.5 scenario (Box 1). The RCP 8.5 is characterised by increasing greenhouse gas emissions over time and represents scenarios in the literature leading to high greenhouse gas concentration levels. This high-forcing scenario shows significant changes in the climate system, which identify the contribution of human-caused warming to climate impacts, as compared with natural variability.

WorldClim (http://www.worldclim.org) is a database of high spatial resolution global weather and climate data that is widely used for research and related activities. These data can be used for mapping and spatial modeling. WorldClim is developed by Robert J. Hijmans, Susan Cameron, and Juan Parra, at the Museum of Vertebrate Zoology, University of California, Berkeley, in collaboration with Peter Jones and Andrew Jarvis (CIAT), and with Karen Richardson (Rainforest CRC) (Hijmans et al., 2005). The GCMs outputs have been downscaled and calibrated (bias corrected) in monthly average grid of 30 seconds for historical (1960–1990) and future (mid-century is 2041–2060) precipitation and temperature (minimum, mean, and maximum temperature and total precipitation).

RCP 8.5 (Representative Concentration Pathways) scenario is used in the IPPC Fifth Assessment report (AR5). In RCP 8.5, emissions continue to rise throughout the 21st century. This scenario combines assumptions about a high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and Green House Gas emissions in absence of climate change policies.

Box 1 *About WorldClim data and RCP8.5*

A model selection process was conducted to identify the most three appropriate GCMs provided by WorldClim for the climate change assessment at the four Ramsar sites. The selection process consisted of the following steps:

Step 1: Initial selection of GCMs

The initial selection was based on an evaluation of climate models that have been used in recent studies in India (i.e., CORDEX-SA models used for the Pong basin and the national assessment in 2020). From the evaluation, 10 common GCMs used in these studies that demonstrated good performance were selected for further steps. The 10 GCMs were CCSM4, CNRM-CM5, GFDL-CM3, HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM, MIROC5, MPI-ESM-LR, MRI-CGCM3 and NorESM1-M.

Step 2: Refined selection based on projected changes in precipitation and temperature

Climate projections derived from the 10 GCMs (seasonal and annual changes in temperature and precipitation - ΔT and ΔP) were compared against projection results reported in recent studies where relevant (i.e., projections reported for the Pong basin and the national assessment in 2020) (Figure 25 and Figure 26). From the comparison process, three GCMs that produced the most consistent projection results with current studies were then selected, including CCSM4, HadGEM2-ES and MIROC-ESM. Brief descriptions of these models are shown in Box 2.

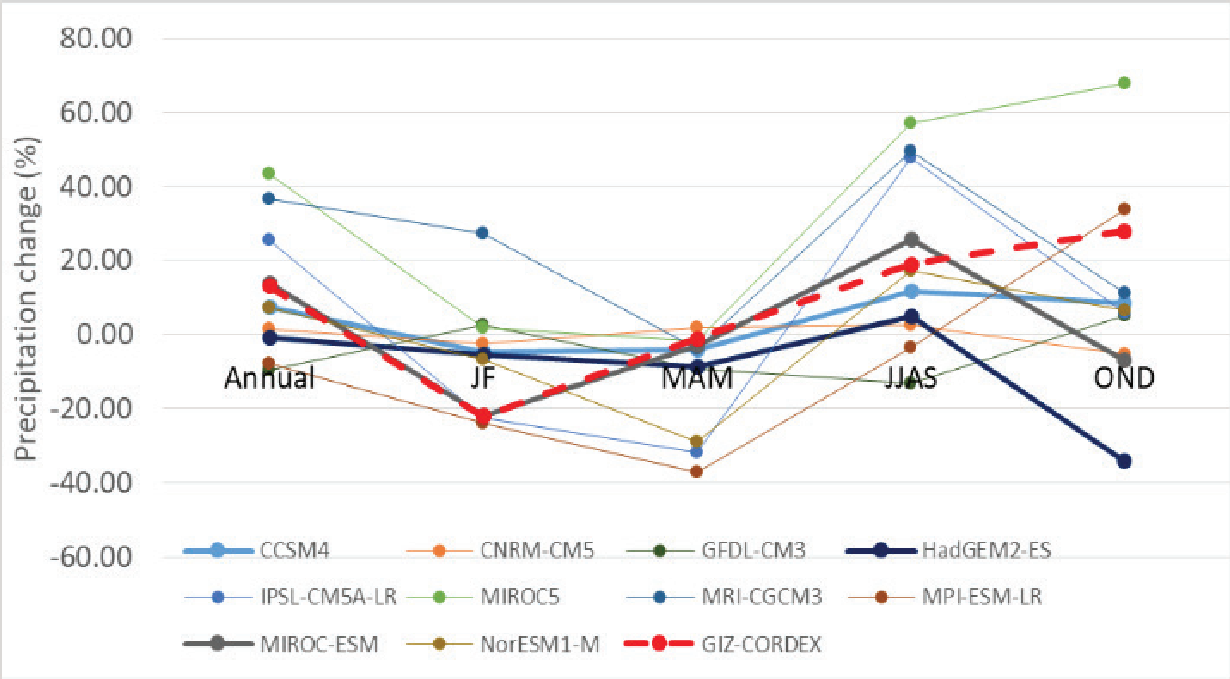

Figure 25 *Changes in precipitation in the Pong basin by 2050s derived from the 10 GCMs in comparison with results reported by CORDEX-SA models (GIZ). The three selected GCMs are the thicker lines.*

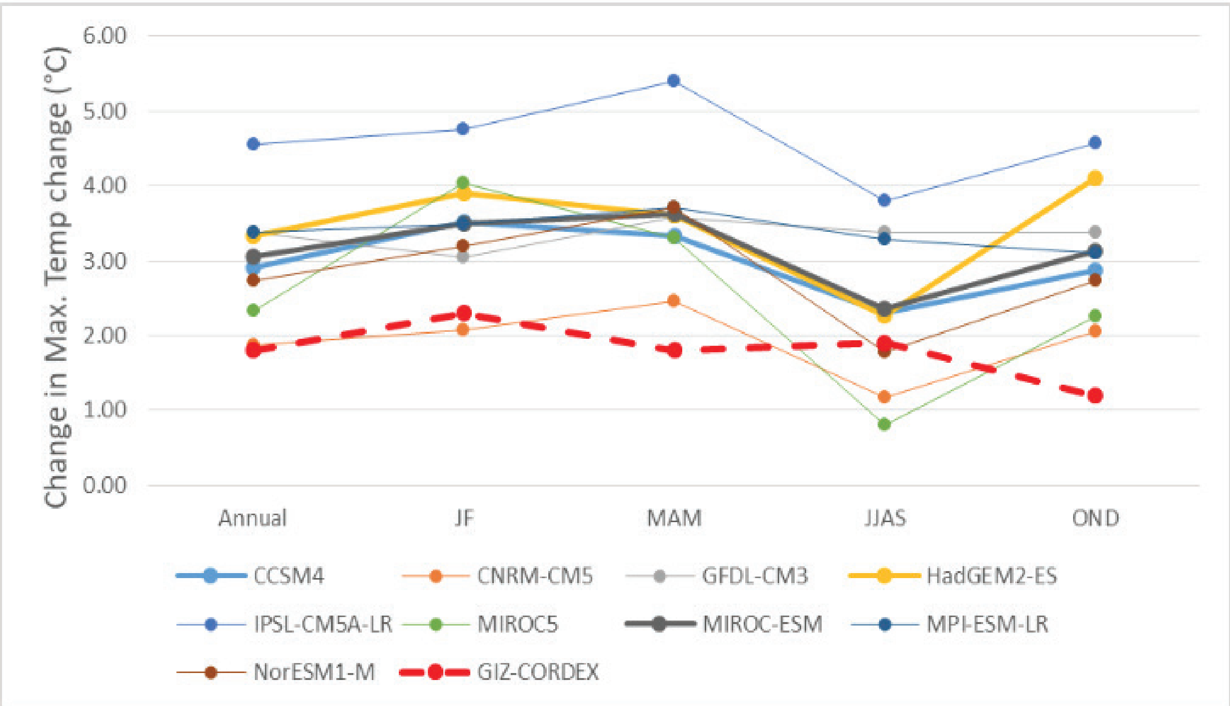

Figure 26 *Changes in temperature in the Pong basin by the 2050s derived from the 10 GCMs in comparison with the results reported by CORDEX-SA models (GIZ). The three selected GCMs are the thicker lines.*

The Community Climate System Model version 4 (CCSM4) is a general circulation climate model consisting of atmosphere, land, ocean, and sea ice components that are linked through a coupler that exchanges state information and fluxes between the components. The CCSM4 has been widely used to study several paleoclimate epochs, the climate of the more recent past, and to make projections of possible future climate change. The CCSM4 was made available to the community in April 2010 with significant improvements compared to the previous version, CCSM3. CCSM4 produces El Niño–Southern Oscillation variability with a much more realistic frequency distribution than in CCSM3. Changes to the CCSM4 land component lead to a much improved annual cycle of water storage, especially in the tropics. The CCSM4 sea ice component uses much more realistic albedos than CCSM3, and for several reasons the Arctic sea ice concentration is improved in CCSM4. Further information for CCSM4 can be found in Gent et al. 2011 (https://journals.ametsoc.org/view/journals/clim/24/19/2011jcli4083.1.xml)

The Hadley Centre Global Environment Model version 2 – Earth System (HadGEM2-ES) is a configuration of HadGEM2 family developed by Met Office Hadley Centre. HadGEM2-ES represents interactive land and ocean carbon cycles and dynamic vegetation with an option to prescribe either atmospheric CO_2 concentrations or to prescribe anthropogenic CO_2 emissions and simulate CO_2 concentrations. HadGEM2-ES has a high climate sensitivity of approximately 4.6°C for a doubling of CO_2 that places it near the top of the range (2.1°- 4.7°C) of the CMIP5 models. An interactive tropospheric chemistry scheme is also included, which simulates the evolution of atmospheric composition and interactions with atmospheric aerosols. Taking into account climate change projections from models with higher sensitivity could lower the chance of a planned adaptation turning out to be inadequate, assuming that the range of model sensitivity is satisfactorily captured. Further information for HadGEM2-ES can be found in Martin et al. 2011 (https://gmd.copernicus.org/articles/4/723/2011/gmd-4-723-2011.pdf).

The Model for Interdisciplinary Research on Climate – Earth System Model (MIROC-ESM), is based on a global climate model MIROC which has been cooperatively developed by the University of Tokyo, Japanese National Institute for Environmental Studies (NIES), and Japan Agency for Marine-Earth Science and Technology (JAMSTEC). On the basis of MIROC, MIROC-ESM further includes an atmospheric chemistry component (CHASER 4.1), a nutrient-phytoplankton-zooplankton-detritus (NPZD) type ocean ecosystem component, and a terrestrial ecosystem component dealing with dynamic vegetation (SEIB-DGVM). Further information for MIROC-ESM can be found in Watanabe et al. 2011 (https://gmd.copernicus.org/articles/4/845/2011/gmd-4-845-2011.pdf).

Box 2 *Briefs of GCMs selected for climate projections at the Ramsar sites*

Step 3: Climate change projections for the Ramsar sites

For each of the Ramsar sites, a Multi-Model Ensemble (MME) of the three selected GCMs' (i.e., CCSM4, HadGEM2-ES and MIROC-ESM) data was generated with annual and seasonal changes in precipitation and temperature (presented in Chapter 3). It has been widely demonstrated that using the ensemble mean method for multiple GCMs can reduce uncertainties in climate change projections in comparison with using a single GCM.

- Hydrologic assessment and impact of hydraulic structures

Since the study sites are located mostly in the downstream areas, which are influenced by local changes and upstream development, understanding the study areas' future conditions in the broader geographic and hydrological context is an important part of the vulnerability assessment. The hydro-ecological studies already carried out for the GIZ wetland management project provide much of the background for understanding the hydrological conditions of each site. Those studies should include climate change input and social development input such as land-use changes, hydraulic constructions, water reallocation projects and waste/wastewater disposal. Also, the intensification of agriculture increases sediment loads in drainage corridors and the use of fertilisers, which eventually are transported to delta regions through land runoff and river discharge, which are significant at Bhitarkanika and Point Calimere.

9.1.5 Assessment of climate change impacts

For each of the Ramsar sites and the targeted assets, the exposure, sensitivity, impact and adaptive capacity were defined using the baseline and climate threat modelling results and CAM matrix support tools. All the wetland ecosystems and species will be affected by climate change, depending on their sensitivities to the changes, their abundance, their interdependence with other species and elements in their environment and their ability to adapt. Species' responses to climate change will be influenced by the actions that wetland managers, and linked sectors and communities, take to address the anticipated impacts.

The assessment of the impacts of climate change on the assets considered two important factors:

- **Exposure** is the extent to which a system is exposed to the climate change threat.
- **Sensitivity** is the degree to which a system will be affected by, or responsive to, the exposure.

The potential **impact** is a function of the level of exposure to climate change threats and the **sensitivity** of the target assets or system to that **exposure**. Figure 27 shows the parameters and issues that were considered in carrying out the impact and vulnerability assessment at the four Ramsar sites.

Photo credit: GIZ

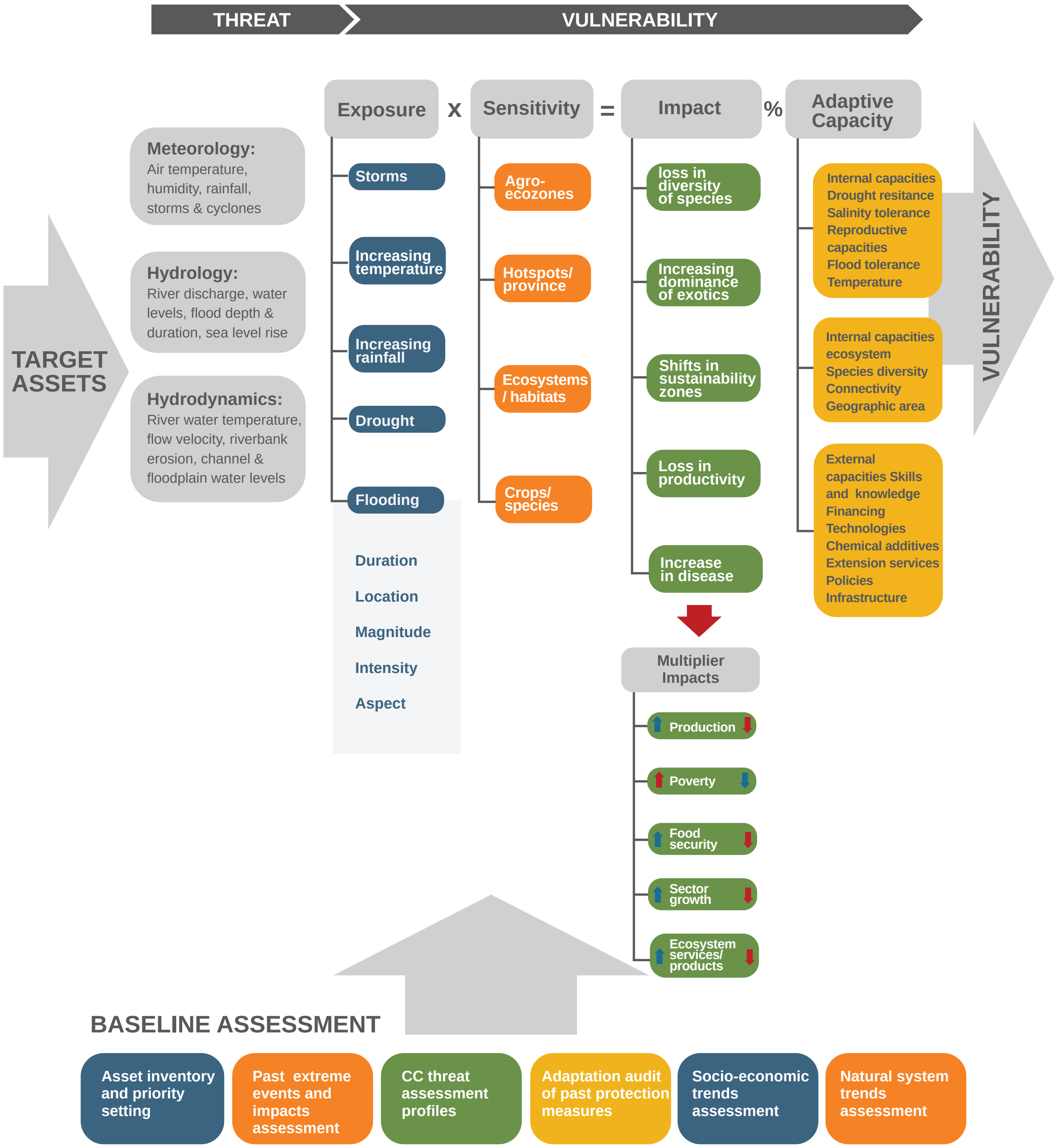

Figure 27 *Illustration of parameters and issues considered in the CAM baseline and vulnerability assessment process*

- Exposure

The rating system for exposure and other parameters used scoring from ‘very low’ to ‘very high’ and was applied on the basis of expert judgement drawing from the best available scientific and factual evidence and where appropriate community knowledge and experience (Figure 28).

VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH
Very low intensity/ severity and/or very infrequent and/or very short duration	Low intensity/ severity and/or infrequent and/or short duration	Medium intensity/ severity and/or average and/or average duration	High intensity/ severity and/or frequent and/or long duration	Very high intensity /severity and/or very frequent and/or very long duration

Figure 28 *Exposure scoring protocol*

- Sensitivity

The next step in impact assessment was to rate the sensitivity, which is the degree to which the exposure to a threat will negatively affect the integrity or operation of the system/asset. Taking into account those variables, the assessment team rated the system sensitivity from very low to very high (Figure 29).

VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH
Species or habitat displays very low sensitivity to extremes in temperature and rainfall, or incidence of drought, flooding, storms and other climatic disturbances	Species or habitat displays low sensitivity to extremes in temperature and rainfall, or incidence of drought, flooding, storms and other climatic disturbances	Species or habitat displays medium sensitivity to extremes in temperature and rainfall, or incidence of drought, flooding, storms and other climatic disturbances	Species or habitat displays high sensitivity to extremes in temperature and rainfall, or incidence of drought, flooding, storms and other climatic disturbances	Species or habitat displays very high sensitivity to extremes in temperature and rainfall, or incidence of drought, flooding, storms and other climatic disturbances

Figure 29 *Sensitivity scoring protocol*

The sensitivity aspects that were also considered for wetland ecosystems, habitats and species include:
Climatically-sensitive habitat: The habitat and its resident species may be dependent on a narrow temperature or precipitation range or seasonal patterns.

Narrow breeding habitat: The species may have a small, preferred breeding range available to them, which limits their populations and possibility of spreading elsewhere.

Rare or threatened: The species or ecosystems may be classified as rare or threatened, e.g., on the IUCN Red List, which would indicate the existing trends and level of threats.

Small or declining range: The species may have a relatively small range that it occupies and due to pressure on the preferred habitats within this range area for expansion or displacement is restricted.

Limited dispersal capacity: The species is not able to move away easily, or seeds to be dispersed, and so is restricted to an area with a deteriorating climate increasingly outside its comfort zone.

Dependent on interspecific relationships: The species in a habitat are usually dependent on each other, e.g., for food, for refuge or for pollination. If one species is displaced by climate changes, its dependent species are also likely to be sensitive.

Stages in life-history dependent on specific climatic triggers: Many species are dependent upon climate triggers such as seasonal temperature change, day length, rainfall at the start of the monsoon and increased flows in rivers, especially for breeding or migration. If these are changed they may become more sensitive.

The CAM tools at this stage consist of a Vulnerability Assessment Matrix as illustrated in Table 12. Scores were noted on this matrix together with footnotes to provide detailed reasons or justification for the score. The product of exposure and sensitivity provided a measure of the potential impact of the threat on the system. The method provided a support tool for determining the impact rating, the impact scoring matrix, shown in Table 13

***Table 12** Vulnerability Assessment Matrix for recording and annotating exposure, sensitivity and impact scoring*

Threat category	Details of Threats	Impact assessment				Adaptive capacity	Vunerability (impact x adaptive capacity)
		Exposure	Sensitivity	Impact level (exposure × sensitivity)	Impact summary		
Seasonal changes							
Temperature increase							
Rainfall							
Extreme event changes							
Coastal flood events							
Upper catchment flash flood							
Storm surge							
Large-scale extreme-level flooding							
Sea-level rise							

***Table 13** Determining impact score from sensitivity and exposure*

		Exposure of system to climate threat				
Sensitivity of system to climate threat		Very Low	Low	Medium	High	Very High
	Very High	Medium	Medium	High	Very High	Very High
	High	Low	Medium	Medium	High	Very High
	Medium	Low	Medium	Medium	High	Very High
	Low	Low	Low	Medium	Medium	
	Very Low	Very Low	Low	Low	Medium	High

The impacts of climate change on each site and its target assets were described in the Vulnerability Assessment Matrix (Table 12). The listed **direct and indirect impacts** provided the basis for defining the adaptation responses. The impacts on wetland ecosystems, habitats and species might include:

Direct impacts

- Alter or lose habitat
- Promote invasive exotics
- Alter timing of biological events
- Transform food webs

- Change growing seasons
- Change species ranges
- Change patterns of seasonal breeding

Indirect impacts

- Loss of NTFPs
- Loss of ecosystem services
- Loss of livelihoods

9.1.6 From impact to vulnerability assessment

The next step in the vulnerability assessment of wetland habitats, species and ecosystem services was to determine their **adaptive capacity** and that of the managing organisation or community to avoid, prepare for and respond to the impacts.

The adaptive capacities were identified as (1) the internal capacity of the species, (2) the internal capacity of the ecosystem and (3) the external capacities of managing organisations and user communities. These are shown in Figure 30. The scoring system for adaptive capacity for external capacities is shown in Figure 31.

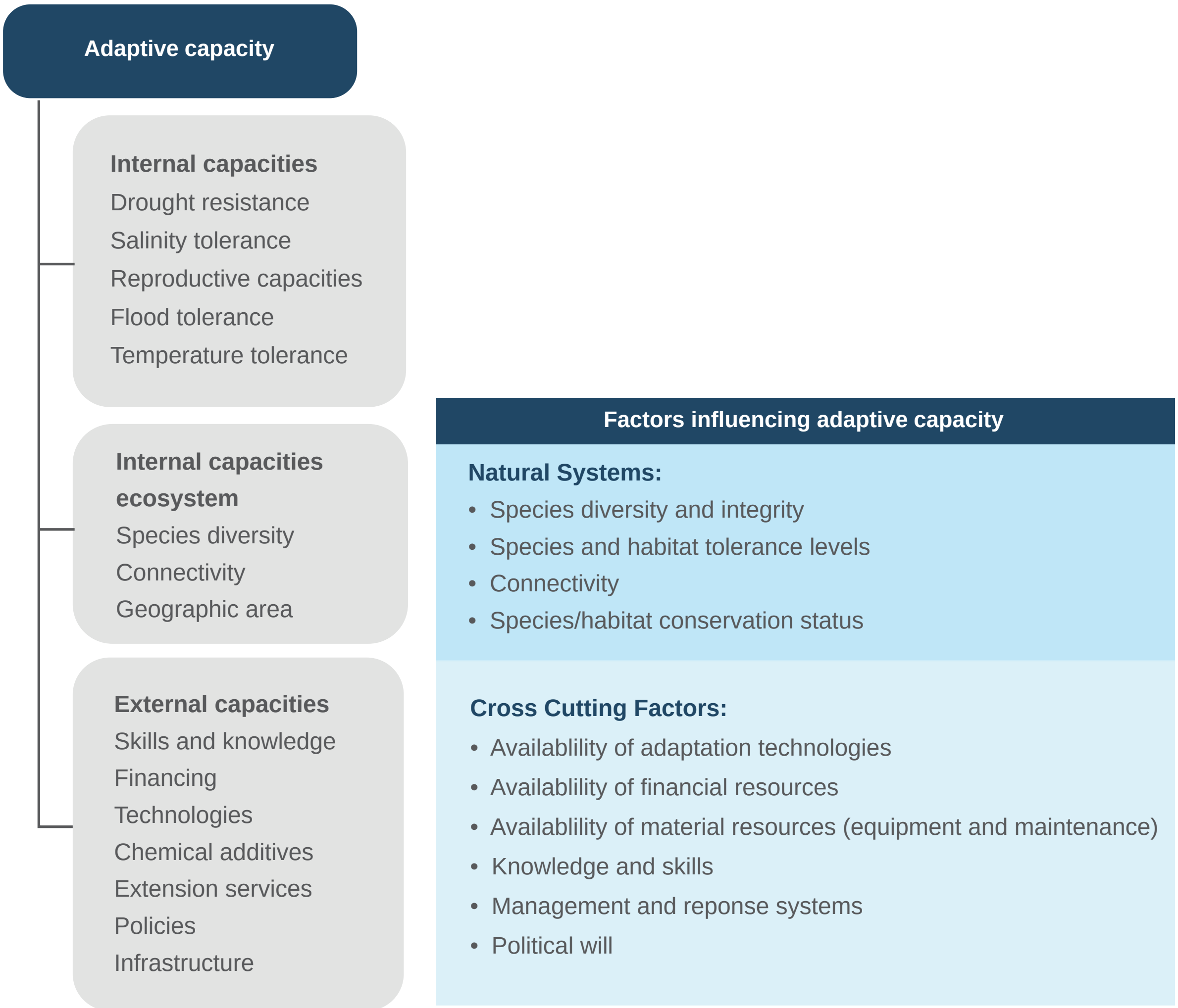

Figure 30 *Adaptive capacities and influencing factors*

VERY LOW	LOW	MEDIUM	HIGH	VERY HIGH
Very limited institutional capacity and no access to technical or financial resources	Limited institutional capacity and limited access to technical or financial resources	Growing institutional capacity and access to technical or financial resources	Sound institutional capacity and good access to technical or financial resources	Exceptional institutional capacity and abundant access to technical or financial resources

Figure 31 *Adaptive capacity scoring for external capacities*

The assessment of the adaptive capacity of the wetlands and their components was drawn from the past scientific evidence base and expert judgements on the innate resilience of the target ecosystems and species to changes and threats. The CAM conducted an analysis of their inherent responses to shifts in temperature and rainfall comfort zones and thresholds, coupled with the institutional capacity of the wetland management agencies and surrounding communities to manage existing threats and future climate changes. The adaptive capacities of existing built structures to reduce the risks of future extreme events were taken into account.

The next step was to determine the final **vulnerability score.** This was done by considering the impact and adaptation capacity together. With increasing severity of impact, vulnerability increases. Adaptation capacity has the opposite effect – with increasing adaptive capacity, the vulnerability of a system decreases. The scoring matrix is shown in Table 14.

Table 14 *Determining the vulnerability score from impact and adaptive capacity*

		Impact				
		Very Low Inconvenience (days)	**Low** Short disruption to system function (weeks)	**Medium** Medium term disruption to system function (months)	**High** Long term damage to system property or function (years)	**Very High** Loss of life, livelihood or system integrity
Adaptive capacity	**Very Low** Very limited institutional capacity and no access to technical or financial resources	Medium	Medium	High	Very High	Very High
	Low Limited institutional capacity and limited access to technical or financial resources	Low	Medium	Medium	High	Very High
	Medium Growing institutional capacity and access to technical or financial resources	Low	Medium	Medium	High	Very High
	High Sound institutional capacity and good access to technical or financial resources	Low	Low	Medium	Medium	High
	Very High Exceptional institutional capacity and abundant access to technical or financial resources	Very Low	Low	Low	Medium	High

9.1.7 Key concepts in the climate change vulnerability assessment

The following concepts were found to be useful in interpreting the sensitivity and adaptive capacity of wetland species and habitats. In this project, these concepts were used to support the vulnerability assessment process at the four Ramsar sites.

9.1.7.1 Shifts in climate, ecology and ecosystem services

Because of climate change, there are likely shifts in the regular climate patterns that will, in turn, lead to ecological and ecosystem service shifts in both space and time as illustrated in Table 15.

Table 15 *Shifts in climate, ecology and ecosystem services*

Climate shifts	Ecological shifts	Ecosystem service shifts
Regular climate shifts	Geographic shifts in species ranges	Diminished ecological provisioning services
Geographic shifts (space) • Latitude and longitude • Elevation	Substantial range losses	Increased reliance on hybrids
	Seasonal shifts in life cycle events (e.g., advances in flowering and fruiting, fish and bird migration)	Diminished wild genetic diversity
	Community composition changes: Warm-adapted species in communities increase – others die out	Reduced crop diversity
Seasonal shifts (time) Onset and end Variability	Body size changes – warming associated with decreased body size	Reduced availability and access to NTFPs
	Genetic changes (e.g., tolerance shifts; stress proteins)	Reduced water availability
	Accelerating loss of populations and species in hot spots (extreme temperatures, coupled with drying - a significant driver of biodiversity loss)	Diminished regulatory and habitat services
Extreme events shifts • Extreme event shifts - intensity, regularity, location • Micro events - e.g., flash flooding and soil loss in uplands • Macro events - e.g.,saline intrusion in delta; cyclone landfall	New ‘problem’ species entering communities	Reduced pollination and pest control
		Reduced soil organic (carbon) content
		Reduced soil microfauna and flora
		Systems requiring more intensive inputs

Geographic shifts are illustrated in Figure 32, showing how the lower (green) area of the original habitat is no longer a suitable habitat and shifts towards the upper (blue) area. Temporal shifts are illustrated in Figure 33, with climate change increasing the frequency (number of days) with increased maximum temperature, which could be indicative of the duration of heat waves.

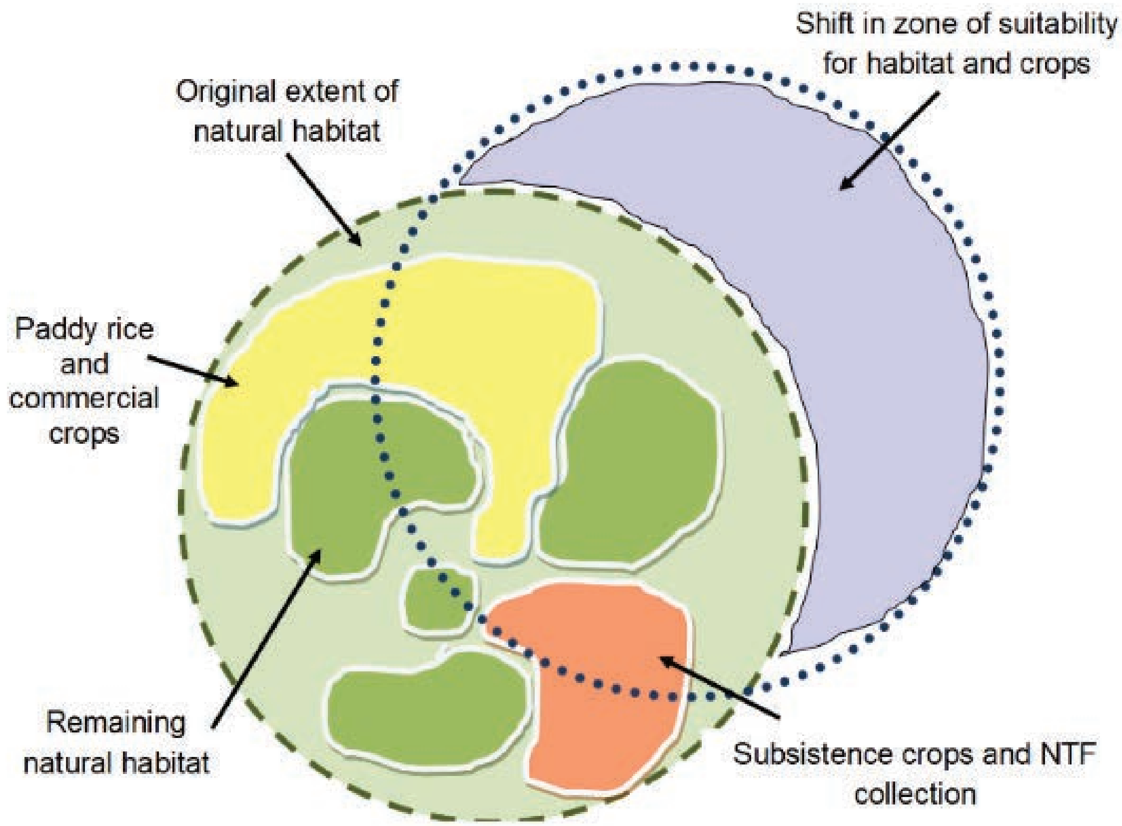

Figure 32 *Illustration of a geographic shift in suitability for habitat*

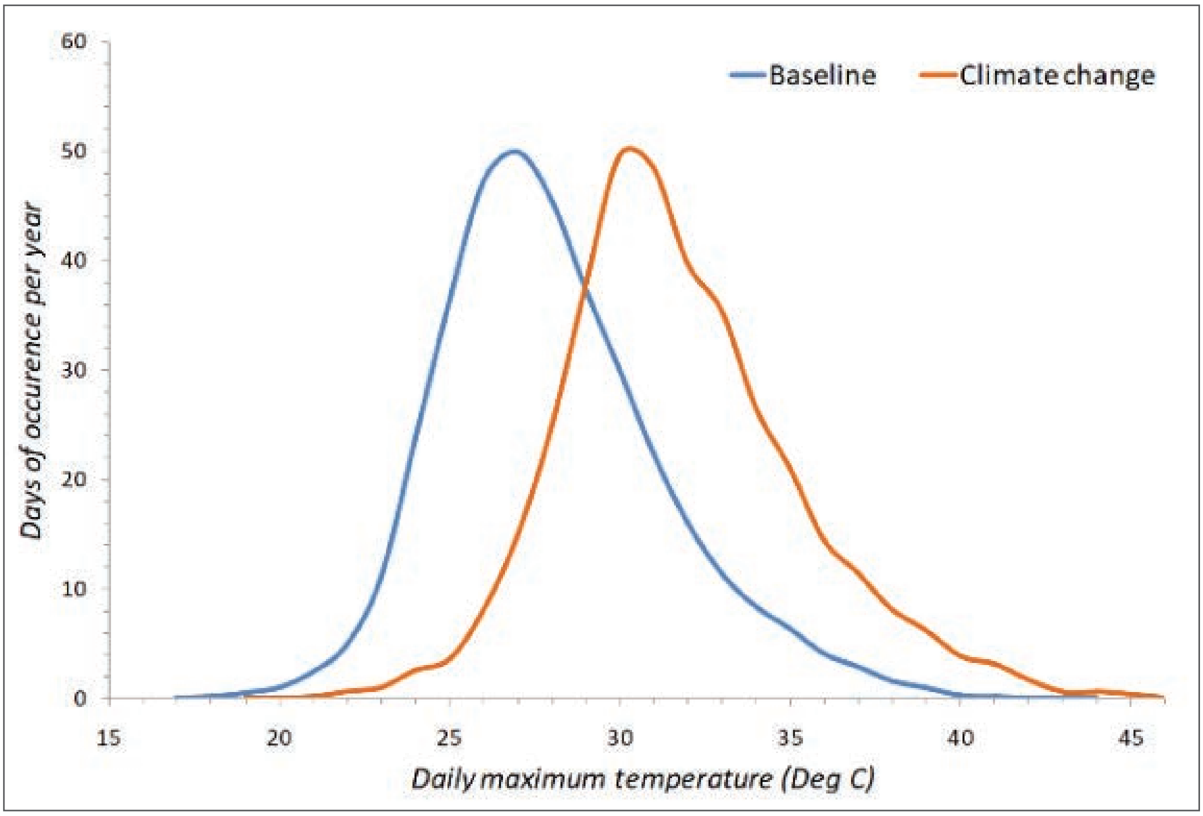

Figure 33 *Temporal shift increasing number of days with increased maximum temperature*

9.1.7.2 Species and habitat comfort zone analysis

Comfort zones are where species and ecosystems experience the most suitable growing conditions in terms of the range and timing of temperature and rainfall. ICEM defines comfort zones to include 50% of the baseline variability in temperature and rainfall for typical months, seasons and years about the mean. In Figure 32, the comfort zone is shown in the blue box and whisker charts reflecting the variability of the baseline daily maximum temperatures in the wet and dry seasons. The orange box and whisker charts show how the projected daily maximum temperatures with climate change will be well outside the comfort zone in the wet season and partially outside it in the dry season. This example is based on an assessment of dipterocarp forests in a protected area in Cambodia. The comfort zone is defined using 25 years of past climate records.

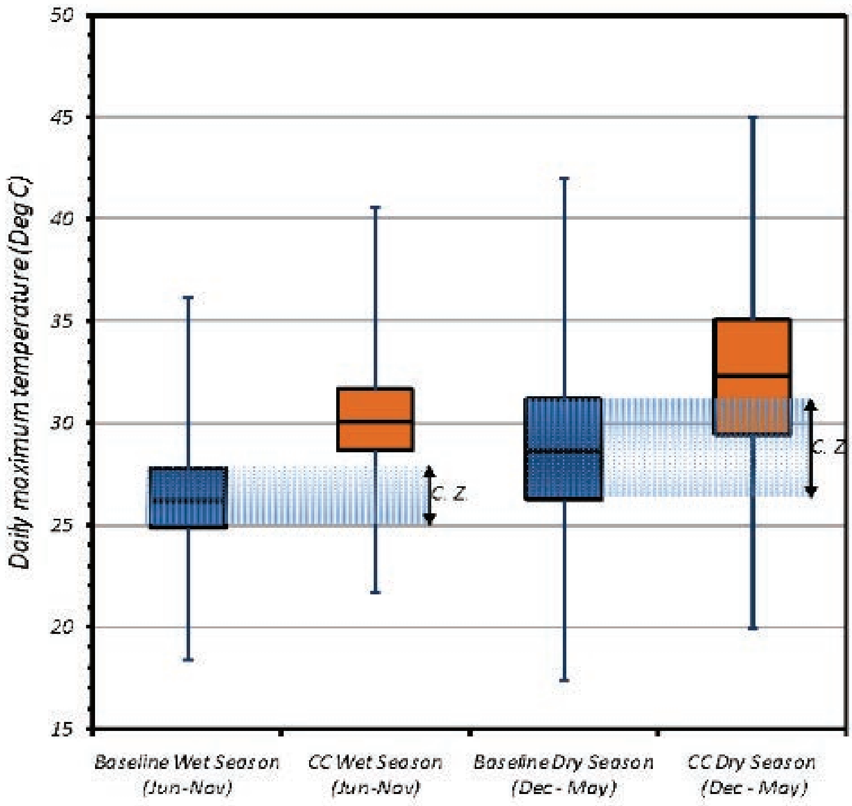

***Figure 34** Illustrating comfort zones: Daily maximum temperatures in the wet and dry seasons*

Each habitat and species has different seasonal comfort zones for temperature and rainfall, and we try to define these for the target assets with references to the literature on their natural range, their growing requirements and their breeding cycle requirements, for example. There are databases such as the FAO Ecocrop database[51], CABI Forest Science database[52], FishBase[53], the Reptile database[54], the IUCN Red List data[55] and the India Biodiversity database[56], which may be used to source this information for the species or similar surrogate species (if detailed species-specific data are not available).

9.1.7.3 Geographic hot spots

The identification of geographic hotspots or areas that may be highly vulnerable to climate change (e.g., areas projected to experience much hotter temperatures or drier climates than the surrounding areas may also help in the assessment of species vulnerability and indicate areas where shifts and changes in vegetation are likely to occur). Examples of India-wide hotspot identification are shown in Figure 35, and Figure 36 shows how vulnerability hot spot maps can be developed from increased temperature impacts.

[51] http://ecocrop.fao.org/ecocrop/srv/en/home
[52] https://www.cabi.org/forestscience/forest-trees/
[53] https://www.fishbase.de/
[54] https://reptile-database.reptarium.cz/
[55] www.iucnredlist.org
[56] https://indiabiodiversity.org/

Hot spots may be defined according to the exposure to significant climate change relative to base conditions or exposure to new climate/hydrological conditions. They may also be defined by the sensitivity of the predominant habitats or vegetation to changes such as limited temperature and moisture tolerance ranges, degraded and/or under acute pressure, severely restricted geographic range and rare or threatened species. Alternatively, low adaptive capacity hot spots could be defined by mapping poor connectivity, low diversity and tolerances or homogenous systems.

The climate change projection maps that have been developed for each site provide an indication of the changes expected at the Ramsar site in relation to the surrounding areas, which may indicate exposure hot spots.

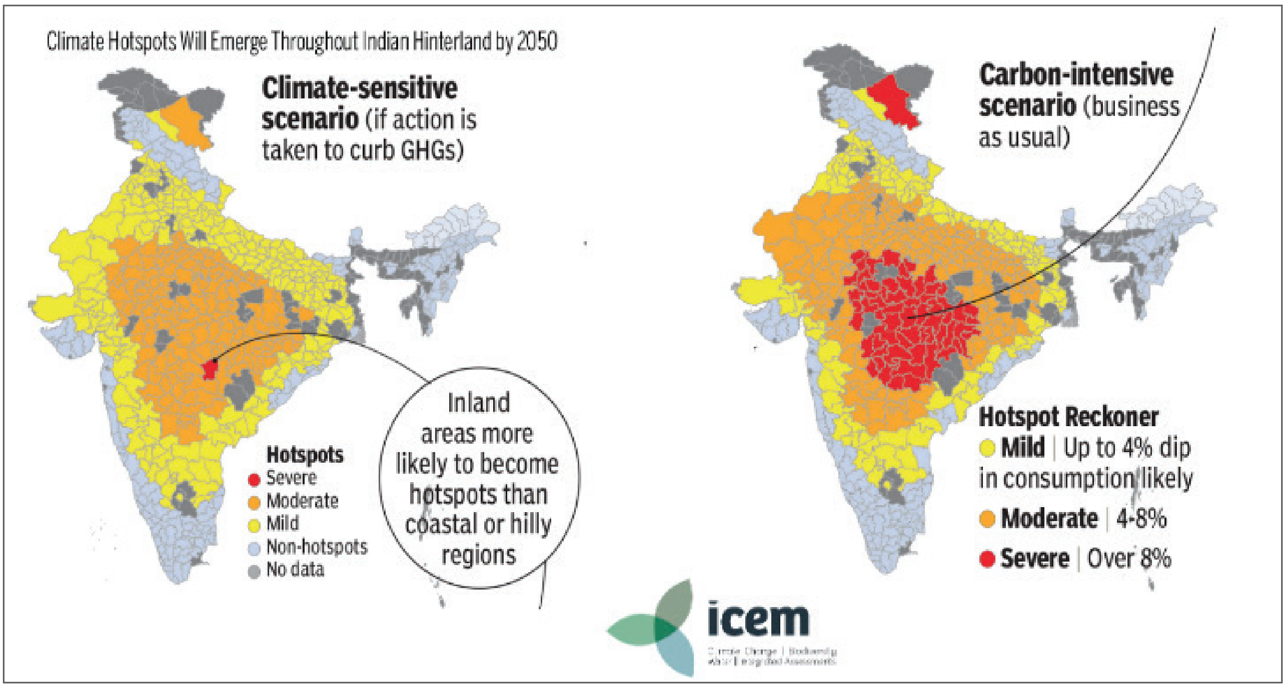

Figure 35 *Examples of India-wide temperature-defined hot spots under two climate change scenarios (Source: Mani et al. 2018)*

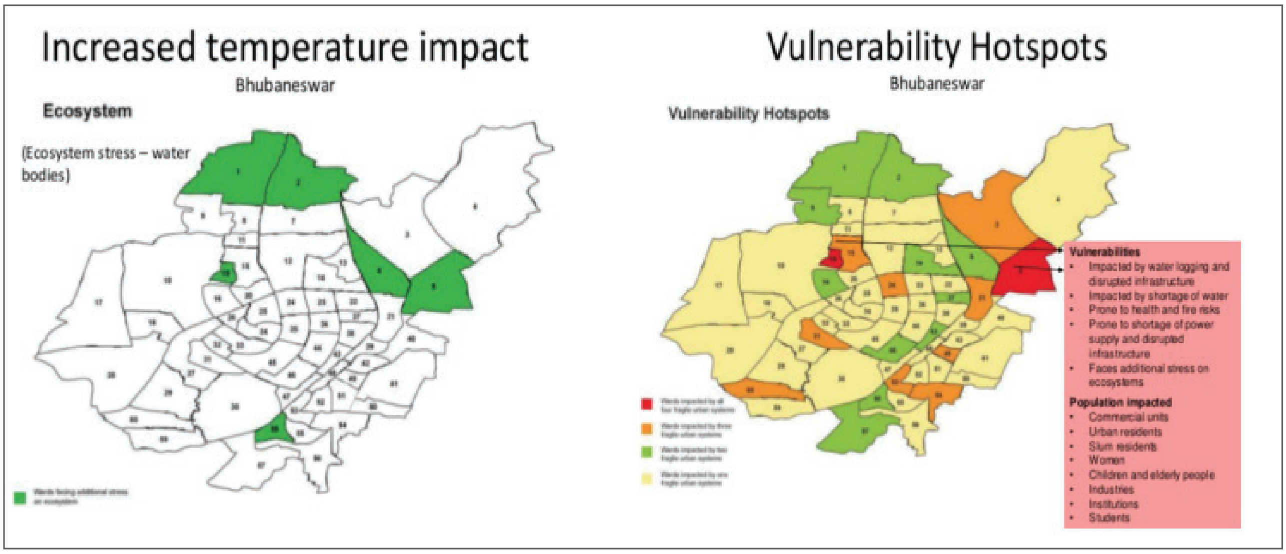

Figure 36 *Example for developing vulnerability hot spots from maps of increased temperature impact (Source: Dr W G Prasanna Khumar, Centre for Climate & Disaster Management, https://www.slideshare.net/wgpkumar/climate-change-and-india)*

9.1.7.4 Climate change and ecological zones

The zoning of ecological and climate characteristics provides a useful visual method for comparing areas with similar characteristics and for noting climatic shifts. Ecological zones may have detailed biophysical descriptors of elevation, temperature, rainfall and landform, and natural system descriptors with vegetation, soils and agricultural, livestock and fisheries profiles. For instance, Figure 37 shows the zones for soil moisture content in Odisha on a particular date.

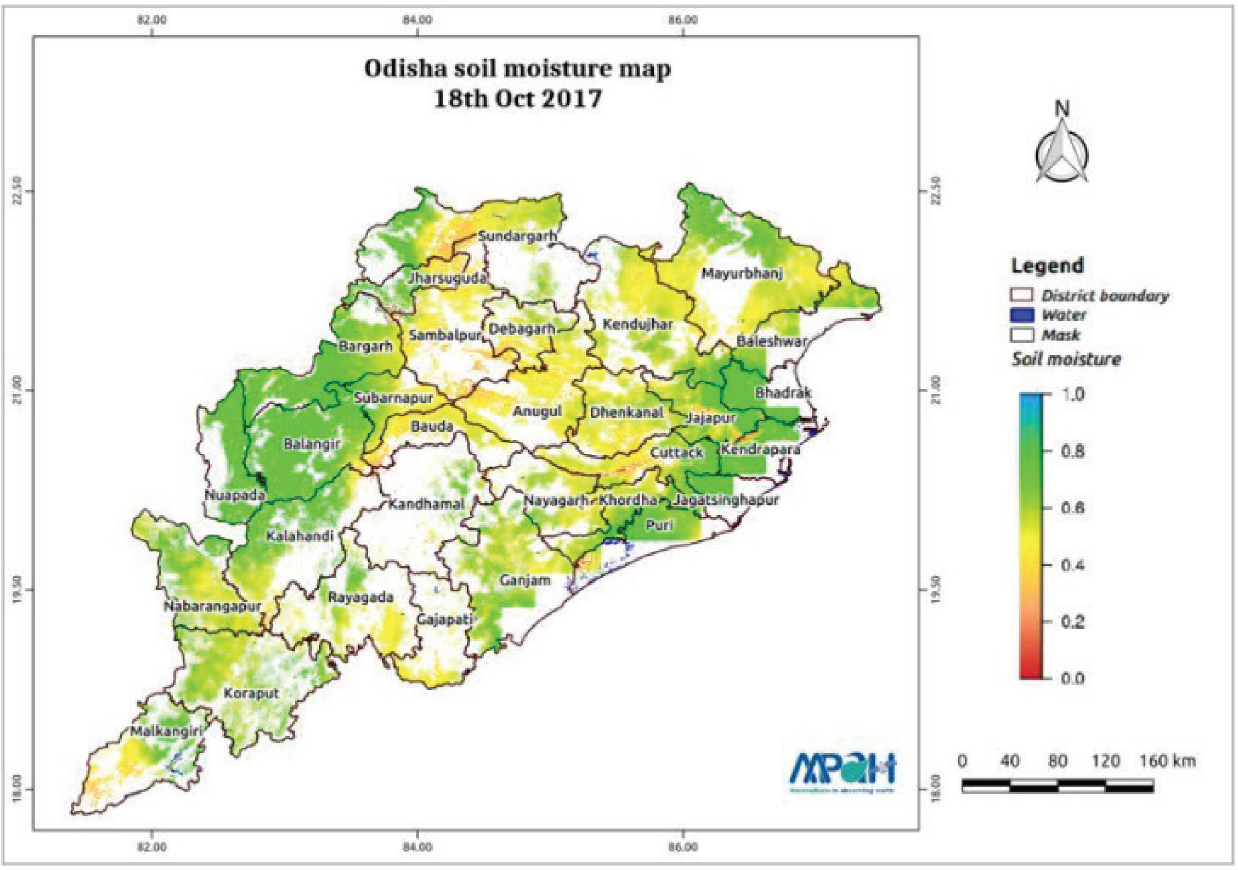

Figure 37 *Odisha soil moisture zonal map*
(Source: Aapah Innovations, http://www.aapahinnovations.com/soil-moisture-map-state-odisha-2/)

Bio-climate zones for each of the four Ramsar sites have been prepared from the Global Environmental Stratification (GEnS_v3) data used to prepare a global dataset of bioclimate using four variables: (i) growing degree-days on a 0°C base[57] (GDD), reflecting latitudinal and altitudinal temperature gradients; (ii) the aridity index (Trabucco et al., 2008), which forms an expression of plant-available moisture; (iii) temperature; and (iv) potential evapotranspiration seasonality, which expresses both seasonality and continentality (Metzger, 2013). The two Ramsar sites in Himachal Pradesh have greater variations in adjacent bioclimatic zones into which they may be shifted with climate change. The two coastal sites are more uniform, being classified as extremely hot and xeric. The bioclimate zones are shown in the baseline sections of each site.

Climate change zones are mapped for annual and seasonal rainfall and temperature averages and extremes or specific tolerances and thresholds such as extreme events, droughts and floods. An example of this is reflected in the changes in the annual precipitation in the Pong basin (Figure 38). These variables are used in overlays to assess the potential changes in bioclimatic zones.

[57] Reflects the annual sum of daily temperatures above 0°C, a standard variable in vegetation and crop models to determine germination.

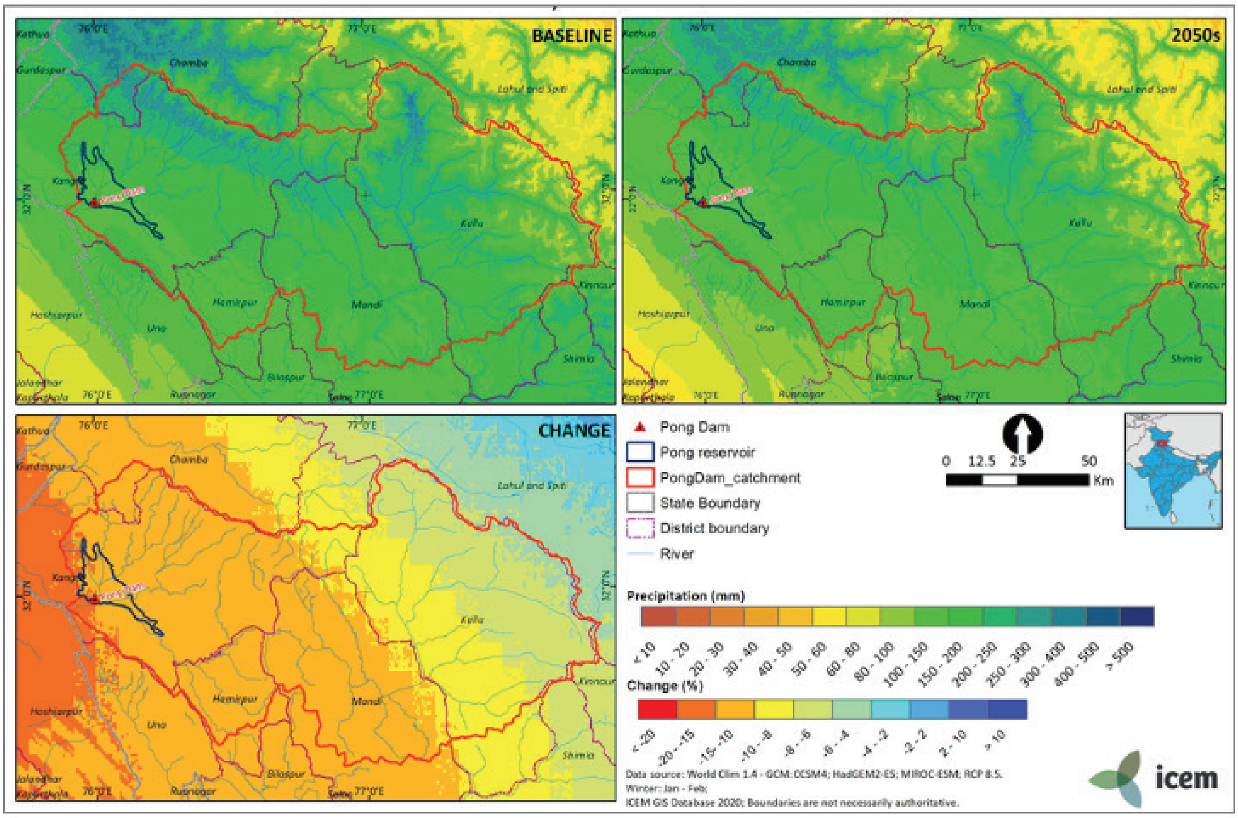

Figure 38 Climate change zonal map – changes in annual precipitation in the Pong basin

9.1.8 Ecosystem-based adaptation planning

Adaptation measures can be taken to address different stages of the vulnerability assessment cycle. Threats of climate change are best addressed through mitigation measures, by minimising the extent to which the asset is exposed to the climate event, or by reducing the sensitivity of the asset. Reduction of non-climate threats is also considered as an adaptation option. Perhaps the most straightforward adaptation measures may be through building the adaptive capacity of the asset or of the management agency and wetland users (Figure 39).

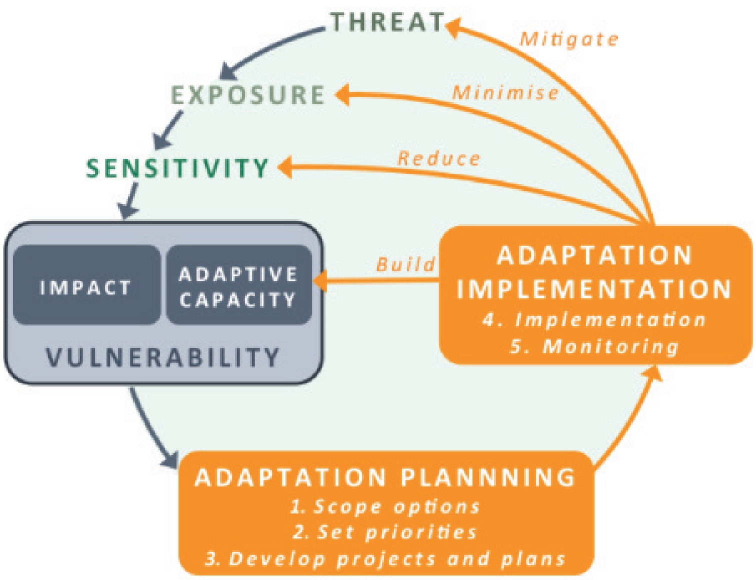

Figure 39 *Schematic of adaptation options to address climate change impacts on an asset*

An Ecosystem-based Adaptation (EbA) is the integrated management of land, water and living resources to promote conservation and equitable sustainable use. Consistent with the ecosystem-based principles, ICEM's analysis of key wetland assets and livelihoods considers the interactions with and between the plants and animals that sustain socio-economic activities. ICEM's approach to EbA recognizes:

- the importance of relationships between all parts of the socio-economic system and its surrounding environment
- the distinctive character and tolerance levels of each ecosystem to change
- the different spatial levels of ecosystems that are important to social-ecological system health and productivity (from soil to ecozone)
- the services that assemblages of wild species and other natural resources provide to social-ecological systems
- the importance of healthy ecosystems as the foundation for adaptation in social-ecological systems

The CAM Adaptation Planning builds on the vulnerability assessments to develop a range of options and then determine priorities (Figure 40). In situations of limited resources, it is not possible or necessary to do everything at once – choices need to be made on what is feasible now and what can be left to later planning cycles.

1. Review the most vulnerable assets	2. Looking back to define the impacts which require adaptation responses	3. Defining the adaptation options	4.Setting priorities among options	5. Integrating adaptation priorities	6. Building adaptation packages into plans and projects
To identify (I) the assets which have been assessed as most vulnerable in the CAM VA process and (II) threats to which those assets that are most vulnerable	For the most vulnerable assets - Identify the most significant impacts which will require adaptation responses	For each vulnerable asset define a range of adaptation options for the species group, habitats, ecosystems which address the most significant impacts	Define which options (I) are most important, (II) have the greatest chances (III) are feasible (IV) do not have negative effects on other sectors or other adaptations (now or in future) Also identifying the the order of adaptationand needed phasing - or what needs to be done now or what can be left for later	Identifying synergies and needed linkages between adaptation priorities. For each priority define key activities. Integrate priorities as adaptation packages or projects	Prepare strategy for 'mainstreaming' into development plans and policies. Preparing design management frameworks for each priority.

Figure 40 *CAM Adaptation Planning process*

Table 16 outlines the ecological principles and options for EbA to be considered in developing the adaptation plans for each of the Ramsar wetland sites. Some of the EbA options will strengthen existing management measures, e.g., those that try to reduce existing threats, such as managing illegal fishing methods or cutting of mangroves. Others will be new and aiming to increase connectivity between wetlands and their surrounding catchment or create refuges for wetland species at times of seasonal extremes.

It is not possible to implement all EbA options. The planning process includes a prioritisation of the long list of adaptation options based on (i) the vulnerability of the species or habitats and the need for immediate, medium or long term action, coupled with (ii) an assessment of the cost-effectiveness of the adaptation options, recognising that some options have higher or lower effectiveness but with different cost implications.

Table 16 Ecological principles and adaption options for individual protected areas or supporting landscapes

Principle	Description	Adaptation options
Reduce stressors that amplify climate impacts	The vigour and ability of species and ecosystems to adapt are greatest in the absence of stressors. Climate can act as a threat multiplier and interact with other stressors to increase susceptibility to disease and drought and reduce the competitive abilities of native plants and animals.	• Control nutrient runoff • Control disease • Increase connectivity • Reduce water diversions • Control invasive species • Reduce disturbances
Sustain or restore ecosystem processes and functions to promote resilience	Preserve fundamental ecosystem properties, such as plant growth (biomass production), decomposition, wetland filtration of nutrients and sediments, and nutrient cycling. These processes contribute to ecological integrity even when species composition and ecosystem structure change.	• Restore degraded vegetation, especially in wetlands and riparian zones • Remove dams and diversions • Restore natural ponds • Ensure sediment delivery to estuaries and deltas
Protect intact, connected ecosystems	Intact and fully functioning ecosystems are more resilient to climate change than degraded systems. Intact systems facilitate the ability of species to adapt to current and future changes.	• Restore vegetation along streams • Remove dams and waterway impediments • Avoid/remove developments that bisect corridors • Establish hedgerows in agricultural lands
Protect areas that provide future habitats for displaced species	Using species distribution and other models, identify, map and protect areas that will support shifts in vegetation and animal distributions and those species displaced by climate change, land-use change, sea-level rise, and the interaction of stressors. These areas will facilitate increased adaptive capacity	• Use species distribution models to anticipate range shifts • Nurture partnerships to protect critical habitats outside the protected area • Reduce barriers to low-lying coastal habitats moving inland
Protect areas that provide future habitats for displaced species	Using species distribution and other models, identify, map and protect areas that will support shifts in vegetation and animal distributions and those species displaced by climate change, land-use change, sea-level rise, and the interaction of stressors. These areas will facilitate increased adaptive capacity	• Use species distribution models to anticipate range shifts • Nurture partnerships to protect critical habitats outside the protected area • Reduce barriers to low-lying coastal habitats moving inland
Identify and protect climate refugia	Climate refugia are local areas that have experienced less climate change compared with the broader surrounding area and are likely to continue to do so in the future. These areas preserve existing populations of species that are more likely to be resilient to climate change and may be a destination for future climate-sensitive migrants.	• Identify potential refugia • Suppress fires near forest refugia • Protect cold-water springs and seeps • Reduce human use and disturbance in refugia • Include areas with high topography diversity in protected areas and protected area networks

(Source: IUCN, 2016)

There are two main steps to be taken for adaptation planning after the identification of the potential adaptation options - assessing the feasibility and the effectiveness of each option. The feasibility is the extent to which each measure can be accomplished or implemented. Factors influencing feasibility that need to be considered include the technical complexity, the capacity of the implementing agencies and user community, the availability of equipment and materials and the cost.

The effectiveness of an adaptation option is the degree to which it will be successful in avoiding or reducing the negative impacts of climate change on the target system and enhancing any benefits and opportunities that may arise.

Three questions that can be asked to assess effectiveness are:

- Can the impact be avoided completely?
- If not, to what extent will it deal with the impact?
- How long will the adaptation measures last?

The options may then be scored for both feasibility and effectiveness in a similar range as vulnerability as shown in Table 17 and prioritised using the adaptation matrix of feasibility and Table 18.

Table 17 *Scoring range for the effectiveness of adaptation options*

	Very Low	Low	Medium	High	Very High
Can the impact be avoided completely?	Not at all		Partially	Not at all	Yes
To what extent will it deal with the impact?	< 25%	25% - 50%	50 - 75%	65 - 90%	100%
How long will the adaptaton measure last?	1 year	2 year	2 - 10 years	10 - 20 years	Permanent

Table 18 *Scoring of feasibility and effectiveness for prioritising adaptation options*

		Effectiveness in dealing with impact				
Feasibility of action		Very Low	Low	Medium	High	Very High
	Very High	Medium	Medium	High	Very High	Very High
	High	Low	Medium	Medium	High	Very High
	Medium	Low	Medium	Medium	High	Very High
	Low	Low	Low	Medium	Medium	High
	Very Low	Very Low	Low	Low	Medium	High

The results of the adaptation planning are recorded in the adaptation matrix as illustrated in table 19, which targets a diversion weir for an irrigation system in Nepal. That example showing part of the adaptation matrix results for the irrigation system also includes columns for assessing the significance of impacts normally applied for major infrastructure projects – an optional step that we do not apply in the Ramsar site studies. The significance assessment considers the likelihood or chances of the impact occurring and the seriousness of those impacts. Whether or not the significant step is included in the adaptation assessment, it is critical that reasons for the scoring are recorded in detailed footnotes.

Table 19 The Adaptation Matrix – an example from assessment of an irrigation system in Nepal

Threats	Impacts	Significance			Adaptation options	Priority adaptation		
Insert all high or very high threats - first for the system as a whole and then for each of the most vulnerable components (i.e H or VH)	Insert the impacts recorded for H and VH threats (only consider direct impacts)	**Likelihood** the chances of the impact occuring	**Seriousness** the impact - e.g. loss of life, property	**Significance** of the impact - for the system objective	Listing of the adaptation options in addressing each of the most significant impacts - focus on structuring and bioengineering options	**Feasibility** e.g. cost, skills, staff, equipment, access	**Effectiveness** i.e. how well does it avoid,reduce or eliminate the impact	**Priority**
Intake Structure • Increased river • Flash floods	1. Further damage to diversion weir 2. Unable to raise water levels to reach intake 3. Intake becomes blocked with debri 4. Sediment enters main	VH[17] H[18] VH[19] H[20]	H[21] H[22] H[23] M[24]	VH H VH M	1. Rebuild diversion weir and intake taking CC into account 2. Improved river bed protection downstream of core wall 3. Increased maintenance/ unblocking of existing	L[25] M[26] M[27]	VH[28] H[29] H[30]	H H H

17 100 year return period flood increases in size by 50% increasing scouring of khola bed material
18 Damage to the weir crest level by increased flood volumes
19 Rainfall intensifies increasing by 20% causing the catchment area in Churia mountains being mostly forested area but steep more liable to landslides and debris flows
20 Average monthly flows increasing during the pre-monsoon period with a maximum increase in July will bring more sediment into the main canal
21 Increasing likelihood of diversion structure completely collapsing
22 Reduction in volume of irrigation water entering the main canal
23 Approaches to the headworks and the intake gate becoming inoperable due to sediment build up

9.2 ANNEX 2 – VULNERABILITY ASSESSMENT MATRICES

The matrices are attached as complementary materials.

Table 20 Attached files of Vulnerability Assessment Matrices

TARGET ASSET	ATTACHED FILE
Point Calimere Sanctuary	AAS2010-REP-002-03F Final Report Point Calimere (Annex 2.1 VA_Sanctuary).docx
Muthupet and Thalainayar mangroves	AAS2010-REP-002-03F Final Report Point Calimere (Annex 2.2 VA_Mangroves).docx
Mudflats and associated shallow waterbodies in Great Vedaranyam Swamp	AAS2010-REP-002-03F Final Report Point Calimere (Annex 2.3 VA_Vedaranyam_Swamp).docx

Annex 2.1 - Vulnerability Assessment Matrix for the Point Calimere Sanctuary

ASSET NAME: POINT CALIMERE SANCTUARY

ASSET DESCRIPTION: Tropical dry-evergreen forest covers nearly 15 km2 of Point Calimere Wildlife sanctuary and it is one of the best-preserved. The forests are mostly of the nature of scrubland that stands on low sand-dunes located on the western half of the sanctuary. *Manilkara hexandra,* locally called *Palai* is the most important dominant dry evergreen tree species of the sanctuary. *Lannea coromandelica* which is an introduced species is the only deciduous species found in this forest. In this forest, about 154 species of medicinal plants like *Mucuna pruriens, Solanum trilobatum, Tinospora cordifolia, Randia dumatorum* and *Cissus quadrangularis* were observed. The dominant grass in the grassland is *Aeluropus lagopoides,* followed by *Sporobolus tremulus* and *Cressa cretica* which the herbivores like xxx depend on. The sand-dunes are largely colonised by *Prosopis juliflora* and *Calotropis gigantea.* Sandy beaches are used by nesting Olive Ridley turtles. In total, 364 flowering plants have been identified from inside the park in which 198 plants are used for medicinal and essential food sources of frugivorous mammals and birds. It is home to the largest population of the endemic Blackbuck *(Antilope cervicapra)* in south India. Other animals of the sanctuary include Spotted Deer *(Axis axis),* Wild Boar *(Sus scrofa)* and Jackal *(Canis aureus).* The Spotted Deer, feral-horse *(Equus caballus)* and the Bonnet Macaque *(Macaca radiate)* were introduced into the Sanctuary. Though agriculture and salt production are the main sources of livelihood around the Bird Sanctuary, cattle rearing also supports the livelihood of villagers during the lean period of farming. The people in villages nearby collect fodder and firewood from Sanctuary. The community lives on the edges of Kodikkarai village and their traditional livelihood was a collection of non-timber forest products from the sanctuary. These practices are now prohibited but not fully eliminated. They now mainly catch the fish and prawns in nearby saltpans and mudflats.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during SW Monsoon (Jun-Sep) and NE Monsoon (Oct-Dec)	For SW Monsoon, increase by 25.3% (+67.7 mm, from 267.6 to 335.3 mm) by 2050s. A more significant increase for immediate upstream areas in the catchment (26.0% or 79.7mm). For NE Monsoon, increase by 13.9% (+113.6 mm, from 816.1 to 929.7 mm) by 2050s. This increase is likely to be concentrated in more intense events	Low	Medium	Medium	**Direct impacts:** • The surface and subsurface water increases; reduction in salinity levels of soil and water; Health of the TDEF improves (+) • The relative humidity increases and it helps in flowering and fruiting (+) • The biodiversity of the sanctuary increase including the grasslands (grazing area for blackbuck) (+) **Indirect impacts:** • Increase in Prosopis colonization and the rain helps in the germination of seeds in the faeces of mammals (-)	Low	Medium

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
					• Nesting places for birds and other animals increased due to an increase of canopy cover (+) • Increased carbon sink potential (+) • Eco-tourism potential increased due to greenery improvement (+) • Improved forest produces (timber and wild fruits) will improve the employment for women and livelihoods of the family (+)		
Decrease of rainfall during summer (Mar-May)	Decrease by 10.7% (i.e., -14.1mm, from 131.1 to 117.0 mm), during summer by 2050s.	Low[1]	Medium	Medium	**Direct impacts:** • Water scarcity for wildlife. Most of the ponds are silted and the surface water became saline due to soil salinity as well as saline water intrusion; Wild animals starve for water and fodder. Grassland becomes degraded and more drought-tolerant plants will tend to colonize. (-) **Indirect impacts:** • Encroachment of drought-tolerant plants like Prosopis in the TDEF areas. (-) • Effluents from salt pans increase the salinity and pollution; Feed for the birds is reduced because of less fishery/mollusc production due to pollutants (-)	Low	Medium
TEMPERATURE							
Increase of temperature during SW Monsoon (Jun-Sep)	For SW Monsoon, the average maximum temperature increase from 34.0 to 36.1ºC (increasing by 2.2ºC by 2050s).	High[2]	Medium	High	**Direct impacts:** • Increase in evaporation; Loss of water in the ponds and small streams affecting the fauna and flora (-) • Loss of grassland; Fodder scarcity; Competition for	Low	High

[1] Since the reduction in rainfall is very less which will not have much exposure.

[2] The increase in temp will be more than 2oC which will have higher exposure to the hazard.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
					animals for grazing area; Crossing the sanctuary for fodder and water by the herbivores (-) • Loss of species diversity; sensitive species will be extinct; pollinators will be impacted leading to poor seed setting (-) **Indirect impacts:** • Reduction in forest produce (wild fruits such as Manilkara and spine guard) as the decrease in relative humidity and increase in temp affect productivity (-)		
Increase of temperature during NE Monsoon (Oct-Dec)	By 2050s, hotter summer, average maximum temperature increase by 2.1ºC from 33.7 to 35.8ºC.	Medium	Medium	Medium	**Direct impacts:** • Precipitation levels increases due to the increase in temp (+) • Increase the chances of cyclone due to the increase in atmospheric temperature (-) **Indirect impacts:** • Flowering and fruiting may be affected due to continuous downpour[3] (-)	Low	Medium
Increase in temperature during summer (Mar to May)	For SW Monsoon, the average maximum temperature increase from 34.0 to 36.1ºC (increasing by 2.2ºC by 2050s).	High	High	High	**Direct impacts:** • Increased evaporation of surface water leading to water scarcity for animals (-) • Less grassland productivity (-) and less area for grazing • Evapotranspiration leads to lesser photosynthetic efficiency (-) • Some tree species shed the eaves (some deciduous plants) to cope with the increase in temperature (-)	Very Low	Very High

[3] Abortion of flowers and young fruits in Manilkara hexandra were noticed due to sudden climatic variations such as drought or heavy rains. In the absence of such adverse environmental conditions, a large number of fruits may be produced, resulting in a mass fruiting event (Gunarathne, R & Perera, Anoma. (2014). Climatic factors responsible for triggering phenological events in (Roxb.) Dubard., a canopy tree in tropical semi-deciduous forest of Sri Lanka. Tropical Ecology. 55.)

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
					Indirect impacts: • Degradation of the ecosystem; Spreading of drought-tolerant plants *Lantenna sp* and *Prosopis* (-)		
Increase of temperature during winter (Jan-Feb)	Average maximum temperature increasing by 1.8ºC during winter by 2050s, from 29.5ºC to 31.2ºC.	Low	Medium	Medium	**Direct impacts:** • May affect the flowering and fruiting (-)[4] **Indirect impacts:** • Less fruit set *(Manilkara)* affecting the income to the poor women(-)[4]	Low	Medium
EXTREME EVENTS							
Sea level rise	For SW Monsoon, the average maximum temperature increase from 34.0 to 36.1ºC (increasing by 2.2ºC by 2050s).	High	Very High[5]	Very High	**Direct impacts:** • Loss of land area of sanctuary due to erosion in the eastern side (-) • Seawater intrusion and low lying areas flooded with saltwater and aquifer becomes more saline (-) • Loss of vegetation due to increase in salinity (-) • Changes in species diversity[6] (-) • Loss of habitat for sea turtle nesting (-) **Indirect impacts:** • Increase in the water spread area (-) • Vulnerability of the area increased due to natural disasters like cyclones(-)	Very Low[7]	Very High
Cyclones	Very high risk of increased frequency of cyclones.	Very High	Very High	Very High	**Direct impacts:** • Loss of TDEF vegetation due to high wind velocity. Many trees will be uprooted; already the Gaja cyclone has been damaged extensively (Nov 2018); Wildlife	Very Low[8]	Very High

[4] Abortion of flowers and young fruits in Manilkara hexandra was noticed due to sudden climatic variations such as drought or heavy rains. In the absence of such adverse environmental conditions, a large number of fruits may be produced, resulting in a mass fruiting event (Gunarathne, R & Perera, Anoma 2014).
[5] Sensitivity to sea-level rise of the front beach area, sand dunes and grasslands, not the dry forest. Check elevation of dry forest.
[6] Grassland areas affected by sea level leading to changes in species towards more saline tolerant plants, like salt marshes.
[7] Only low lying areas affected.
[8] Even though management capacity is high, this particular locality cannot be managed.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					(blackbuck; spotted deer and avifauna) severely affected. Many animals were washed from ashore near Nagapattinam and Vellankanni (-) • Erosion along the shore will be high; Loss of habitat for sea turtle nesting (-) **Indirect impacts:** • Possibility of getting new invasive species brought in by the cyclone (-)		
Storm surge	Low to moderate risk of up to 5 m storm surge	**Medium**	**Very High**[9]	**High**	**Direct impacts:** • Uprooting of vegetation due to storm surge, and increase of salt in the soils around the forest and grasslands, infiltration of storm surge water will affect groundwater (-) • Extensive water flooding over a period of time affects the vegetation in the PC sanctuary (-) • Large areas become saline. • Modifies the topography and geomorphology of the area (sand/sediment transport from the sea) casting over the area affects the soil conditions; siltation of canals and drains (-) **Indirect impacts:** • Livelihood – fishing, salt pan, agriculture and aquaculture will be affected (-) • Poverty levels will increase; Migration of poor coastal communities to urban areas for their living (-) • Salinization of land and water affecting agriculture and other livelihood activities (salt pan; fishing; aquaculture) (-)	**Very Low**[10]	**Very High**

[9] Storm surge will bring saline water into the dry forest area, which are salt sensitive plants.

[10] Plants do not have any adaptive capacity to high salt content brought in from storm surge, Prosopis is more salt tolerant.

Annex 2.1.1 – Scoring matrices

Sensitivity of system to climate threat	Exposure of system to climate threat: Very low	Low	Medium	High	Very High
Very High	Medium	Medium	High	Very High	Very High
High	Low	Medium	Medium	High	Very High
Medium	Low	Medium	Medium	High	Very High
Low	Low	Low	Medium	Medium	High
Very low	Very low	Low	Low	Medium	High

Figure 1 *Determining impact score from sensitivity and exposure*

Adaptive capacity	Impact: **Very low** Inconvenience (days)	**Low** Short disruption to system function (weeks)	**Medium** Medium term disruption to system function (months)	**High** Long term damage to system property or function (years)	**Very High** Loss of life, livelihood or system integrity
Very Low Very limited institutional capacity and no access to technical or financial resources	Medium	Medium	High	Very High	Very High
Low Limited institutional capacity and limited access to technical or financial resources	Low	Medium	Medium	High	Very High
Medium Growing institutional capacity and access to technical and financial resources	Low	Medium	Medium	High	Very High
High Sound institutional capacity and good access to technical and financial resources	Low	Low	Medium	Medium	High
Very High Exceptional institutional capacity and abundant access to technical or financial resources	Very low	Low	Low	Medium	High

Figure 2 *Determining the vulnerability score from Impact and Adaptive capacity*

Annex 2.2 - Vulnerability Assessment Matrix for Muthupet and Thalinayar Mangroves

ASSET NAME: MUTHUPET AND THALINAYAR MANGROVES

ASSET DESCRIPTION: The Muthupet mangrove wetland is located in the southernmost end of the Cauvery delta in Thanjavur and Thiruvarur districts (10o18′ to 10o22′ N latitude and 79o28′ to 79o36′ E longitude). It occupies an area of approximately 12,000 ha, including a 1,700 ha lagoon. The mangrove vegetation is only in a small area of about 1,500 ha. The remaining areas are mostly degraded mudflats. The wetland consists of seven reserve forests namely Palanijur RF, Thamarankottai RF, Maravakkadu RF, Thurukkadau RF, Thambikottai RF, Vadakadu RF and Muthupet RF. *Avicennia marina* is an abundant species followed by *Excoecaria agallocha, Aegiceras corniculatum, Lumnitzera racemosa, Acanthus ilicifolius, Ceriops decandra, Rhizophora apiculata* and *Rhizophora mucronata.* The halophytes namely *Suaeda maritima and S. monoica* are also available in the wetland. Canal fishing, the traditional fishing method is being practised in Vedaranyam. People belonging to 26 coastal hamlets of Vedaranyam with a total population of about 35,900 depending on the fishery and forestry resources of Muthupet.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during SW Monsoon (Jun-Sep) and NE Monsoon (Oct-Dec)	For SW Monsoon, increase by 25.3% (+67.7 mm, from 267.6 to 335.3 mm) by 2050s. A more significant increase for immediate upstream areas in the catchment (26.0% or 79.7mm). For NE Monsoon, increase by 13.9% (+113.6 mm, from 816.1 to 929.7 mm) by 2050s. This increase is likely to be concentrated in more intense events	High	Low	Medium	**Direct impacts:** • The seed dispersal will be • more due to flood water and also it enhances seed germination. Freshwater is important for the seeds to germinate. The growth of seedlings also will be high due to floods. (+) • Reduction of flowering and fruiting due to poor cross-pollination. (-) • Mangroves especially young seedlings are with less stress due to reduction in salinity in the soil (+) Ensured better protection against disasters; coastal erosion (+) • Mangroves will have better canopy cover and the extent will be increased due to freshwater with nutrient-laden sediment supply (+) • The fishery resources will improve in mangroves and the livelihoods of the canal fishers will be benefitting (+) • Populations of Phytoplankton and Zooplankton will increase due to an increase in nutrients due to runoff[1]. (+)	High	Medium[2]

[1] Nutrients such as nitrate and ammonia will be brought by the agriculture runoff will enhance the phytoplankton population which in turn will help the zooplankton and other filter feeders to increase in the wetland

[2] Overall, given the positive impacts, the mangroves have a medium vulnerability.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
					• Mangroves system productivity enhanced (+) • The stability of existing communities of mangrove systems will be improved. • Estuary will be more functional; breeding and nursery ground for fishery resources. Food and shelter for avifauna (+) • Silting of canals (fishbone type canals in the restored areas) and the natural creeks will affect the water flow and tidal flushing (-) • Agriculture runoff with pesticide and fertilizer load affecting the flora and fauna (eutrophication, algal bloom) (-) **Indirect impacts:** • Increased carbon sink potential due to increase in biomass (+)		
Decrease of rainfall during summer (Mar-May)	Decrease by 10.7% (i.e., -14.1mm, from 131.1 to 117.0 mm), during summer by 2050s.	**Low**	**Low**	**Low**	**Direct impacts:** • Shoot dieback disease especially in May and June as the evapotranspiration will be high; Recent years the decrease in rainfall has affected the mangroves in Muthupet. The health of mangroves impacted; Loss of biodiversity (-) • In Muthupet, the true mangrove species belonging to Rhizophoraceae were dominant about 150 years ago but now they are locally extinct due to less freshwater flow. • Saline sensitive species will be losing; now Avicennia is the most dominant species (more than 95%) (-). • Prosopis may increase in the landward side (-)	**Medium**[3]	**Medium**

[3] The adaptive capacity of Rhizophora is low because it is less salt tolerant than Avicennia which has a high adaptive capacity, resulting in a medium adaptive capacity.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
					• Loss of mangrove areas if continued drought and monsoon failure (-) **Indirect impacts:** • Conversion of mangrove area due to degradation; Change in land use - Legally and illegal conversion will happen (-)		
TEMPERATURE							
Increase of temperature during SW Monsoon (Jun-Sep)	For SW Monsoon, the average maximum temperature increase from 34.0 to 36.1ºC (increasing by 2.2ºC by 2050s).	Low	Low	Low	**Direct impacts:** • Though there is an increase in temp the rainfall will reduce the soil salinity and the freshwater will improve the health of mangroves as it brings nutrients (+) • Lack of proper tidal flushing due to poor tidal amplitude (-) **Indirect impacts:** • Reduction in fishery resources in the mangrove canals (-)	Medium	Medium
Increase of temperature during NE Monsoon (Oct-Dec)	For NE Monsoon, the average maximum temperature increase from 29.7 to 31.6ºC (increasing by 1.9ºC by 2050s).	Low	High	Medium	**Direct impacts:** • Increase in soil and water salinity affecting the health of the mangrove (-) • Evaporation of soil water increases; Hypersaline conditions in most of the areas leading to mangrove loss (Shoot dieback); saline sensitive species tend to die (-) • Reduction in photosynthesis due to stomatal closure; No CO_2 exchange. Evapotranspiration high. (-) **Indirect impacts:** • Lack of tidal amplitude leads to poor fishing in canals (except the full moon and new moon days in May) (-) • Growth of fishes will be more due to an increase in metabolic rate (+)	Low	Medium

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase in temperature during summer (Mar-May)	By 2050s, hotter summer, average maximum temperature increase by 2.1ºCfrom 33.7to 35.8ºC.	**Low**	**High**	**Medium**	**Direct impacts:** • Increase in soil and water salinity affecting the health of the mangrove (-) • Evaporation of soil water increases; Hypersaline conditions in most of the areas leading to mangrove loss (Shoot dieback); saline sensitive species tend to die (-) • Reduction in photosynthesis due to stomatal closure; No CO2 exchange. Evapotranspiration high. (-) **Indirect impacts:** • Lack of tidal amplitude leads to poor fishing in canals (except the full moon and new moon days in May) (-) • Growth of fishes will be more due to an increase in metabolic rate (+)	**Low**	**Medium**
Increase in temperature during summer (Mar-May)	By 2050s, hotter summer, average maximum temperature increase by 2.1ºCfrom 33.7to 35.8ºC.	**Low**	**High**	**Medium**	**Direct impacts:** • Increase in soil and water salinity affecting the health of the mangrove (-) • Evaporation of soil water increases; Hypersaline conditions in most of the areas leading to mangrove loss (Shoot dieback); saline sensitive species tend to die (-) • Reduction in photosynthesis due to stomatal closure; No CO2 exchange. Evapotranspiration high. (-) **Indirect impacts:** • Lack of tidal amplitude leads to poor fishing in canals (except the full moon and new moon days in May) (-) • Growth of fishes will be more due to an increase in metabolic rate (+)	**Low**	**Medium**

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase of temperature during winter (Jan-Feb)	Average maximum temperature increasing by1.8ºC during winter by 2050s, from 29.5ºC to 31.2ºC.	**Low**	**High**	**Medium**	**Direct impacts:** • Possibility of increase in soil salinity due to evaporation because of increase in temperature (-) • Young seedlings may be affected due to the increase in temperature **Indirect impacts:** • Growth of fishes will be more due to an increase in metabolic rate (+)	**Medium**	**Medium**
EXTREME EVENTS							
Sea level rise	Very high risk of sea-level rise.	**High**[4]	**High**[5]	**High**	**Direct impacts:** • Loss of mangrove extent due to submergence. Lesser possibility of the vertical elevation of the mangrove floor (substratum) due to less sediment flow (-). The wetlands of 441 and 875 ha are likely to be inundated due to rising sea levels at 0.5 and 1 m[6]. Out of the 348 ha of mangroves (Avicennia species), 14 and 65 ha will be under severe threat, resulting in a loss of 4.13 and 18.54% of mangroves. • Movement of mangroves into the elevated areas – mostly *Prosopis* and halophyte dominant in the fringes (-) • Salinization of the area increased due to seawater inundation and intrusion (-) • Tend to move landward side due to shift in the high tide area; However, the landward movement is not possible because of the land use by the private land-holdings which is used for salt pan, agriculture or aquaculture (-)	**Low**	**High**

[4] The mangroves are susceptible to sea level rise. The mangroves in Tamil Nadu are in low-lying coastal areas and are vulnerable to sea level rise (Kathiresan, 2017). In Tamil Nadu, the mangroves are less dense due to the reduction in river water flow and monsoon failure, and hence the mangrove areas are vulnerable to sea-level rise.

[5] The most vulnerable mangroves to sea level are Avicennia and Sonneratia (Kathiresan, 2017) Avicennia is the dominant species in Muthupet mangroves and they will be affected due to sea level rise.

[6] State Government of Tamil Nadu, 2014. Tamil Nadu State Action Plan for Climate Change.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					Indirect impacts: • Fishing will be reduced due to habitat loss (-) • Vulnerability of the area increased due to natural disasters like cyclones and coastal erosion(-)		
Cyclones	Very high risk of increased frequency of cyclones.	High	High	High	**Direct impacts:** • Loss of mangrove areas. Many trees will be uprooted; already the Gaja cyclone has damaged xtensively (Nov 2018); more than 3 sq km of area reduced as per FSI report (2019). Mangrove has the ability to recoup naturally which was evident from many studies (-) • Siltation of canals and the mangrove areas affecting the water movement and tidal flushing (-) • The Bioshield function of mangroves reduced affecting the lives and livelihoods of the coastal community (-) • Bird nesting and wild animals (jackals, birds) will be affected due to cyclones (-) **Indirect impacts:** • The reduction in the extent of mangroves reduce the fishery ground and the habitat for avifauna (-) Loss of carbon sequestration capacity and release of CO^2 due to the loss of mangrove habitats.	High[7]	Medium
Storm surge	Low to moderate risk of up to 5 m storm surge	Medium	High	Medium	**Direct impacts:** • Extensive water flooding over a period of time kills the young seedlings due to lack of respiration in t he roots)(-)	Low	Medium

[7] Avicennia has high resilience -being shown to recover after cyclone events.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					• Modifies the topography and geomorphology of the coastal area (sand/sediment transport from the sea) affects the free flow of water; siltation of canals and drains (-) • Salinization of land and water are lasting several days in low lying areas. **Indirect impacts:** • Poverty levels will be increased; the migration of poor coastal communities to urban areas for their living. • Salinization of land and water affecting livelihood activities (salt pan; fishing; aquaculture; agriculture). • Loss of carbon sequestration capacity and release of CO_2 due to the loss of mangrove habitats.		

Photo credit: WISA (Harsh)

Annex 2.2.1 – Scoring matrices

		Exposure of system to climate threat				
		Very low	Low	Medium	High	Very High
Sensitivity of system to climate threat	Very High	Medium	Medium	High	Very High	Very High
	High	Low	Medium	Medium	High	Very High
	Medium	Low	Medium	Medium	High	Very High
	Low	Low	Low	Medium	Medium	High
	Very low	Very low	Low	Low	Medium	High

Figure 1 *Determining impact score from sensitivity and exposure*

		Impact				
		Very low Inconvenience (days)	**Low** Short disruption to system function (weeks)	**Medium** Medium term disruption to system function (months)	**High** Long term damage to system property or function (years)	**Very High** Loss of life, livelihood or system integrity
Adaptive capacity	**Very Low** Very limited institutional capacity and no access to technical or financial resources	Medium	Medium	High	Very High	Very High
	Low Limited institutional capacity and limited access to technical or financial resources	Low	Medium	Medium	High	Very High
	Medium Growing institutional capacity and access to technical and financial resources	Low	Medium	Medium	High	Very High
	High Sound institutional capacity and good access to technical and financial resources	Low	Low	Medium	Medium	High
	Very High Exceptional institutional capacity and abundant access to technical or financial resources	Very low	Low	Low	Medium	High

Figure 2 *Determining the vulnerability score from Impact and Adaptive capacity*

Annex 2.3 - Vulnerability Assessment Matrix for the Great Vedaranyam Swamp

ASSET NAME: GREAT VEDARANYAM SWAMP

ASSET DESCRIPTION: The Great Vedaranyam Swamp (GVS), which includes the Panchanathikulam wetland area and an un-surveyed Salt Swamp area, has a long history of salt production. Many domestic and industrial salt works operate in the GVS. There was a great change in land use cover after Tsunami as the salinity levels of ground water increased. People have completely stopped farming activities because of seawater intrusion into farmlands after the tsunami. The impacts of salt works will alter the ecosystem, affecting the flora and fauna of the GVS, besides having possible repercussions on the fisheries of the coast. The flow of fresh water from the River Cauvery is now very less affecting the biodiversity in and around the GVS. The Great Vedaranyam Swamp serves as the spawning and nursing ground for commercially important maritime prawns and fishes, such as *Penaeus indicus, P. monodon, Hilsa ilisha* and *Chanos chanos.* Other than these fishes the swamp has a large population of mullet and exotic *Oreochromis mossambicus (Tilapia mosambica).* Mud crab *Scylla serrata* is a commercially important species from the Swamp. The coast of Point Calimere is an important fish landing site for fishes and prawns from November to February. Both species of flamingos viz., the Greater Flamingo *Phoenicopterus roseus* and Lesser Flamingo *P. minor* inhabit the Great Vedaranyam Swamp. In the 1980s, the Point Calimere supported >10,000 Lesser Sand Plover, >15,000 Black-winged Stilt, >50,000 Black-tailed Godwit, >200,000 Little Stint and >150,000 Curlew Sandpipers (Balachandran 2006[1]), but these have come down <500 between 2007 and 2010 (Mankanndan et al 2011[2]). Compared to previous reports from Tamil Nadu Forest Department Census Records (unpublished data), the abundance of many waterbird species are now becoming very rare and uncommon and declining year after year. In 2002, the Point Calimere coastal area, comprising 38,500 hectares, was declared a Ramsar site (No.1210) and a place of international importance for the conservation of wetland.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during SW Monsoon (Jun-Sep) and NE Monsoon (Oct-Dec)	For SW Monsoon, increase by 25.3% (+67.7 mm, from 267.6 to 335.3 mm) by 2050s. A more significant increase for immediate upstream areas in the catchment (26.0% or	**High**	**Medium[3]**	**High[4]**	**Direct impacts:** • The surface and subsurface water increases; reduction in salinity levels of soil and water; the mudflats will be productive as the less saline water is favourable for phytoplankton and zooplankton to flourish. This in turn enhances the food availability for the birds. (+ve)	**High[7]**	**Medium[8]**

[1] Balachandran S. 2006. The decline in wader populations along the east coast of India with special reference to Point Calimere, south-east India. In: Water birds around the World. Boere, G.C., C.A. Galbraith & D.A. Stroud (Eds.). The Stationery Office, Edinburgh, UK. pp. 296–301.
[2] Manikannan R, Asokan S Mohamed Samsoor Ali A and Madhuramozhi G. (2011). Status, abundance and threats to waterbirds of the Great Vedaranyam Swamp, Point Calimere Wildlife Sanctuary (Ramsar Site), South-east coast of India. Journal of Research in Biology 2: 93-100
[3] Sensitivity to changes in salinity caused by run-off and rainfall
[4] This impact is generally positive.
[7] Given number of positive impacts, the adaptive capacity is rated as high, but with erosion and loss of mudflats being an increasing issue, this will need to be managed more actively.
[8] While many impacts are positive, some significant negative impacts remain to be sorted out, e.g. erosion of mudflats and increase in agriculture and livelihoods.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
	79.7mm). For NE Monsoon, increase by 13.9% (+113.6 mm, from 816.1 to 929.7 mm) by 2050s. This increase is likely to be concentrated in more intense events				• Fishery resources will increase for the fishers who are dependent on fishing (+ve) • Erosion will tend to increase, leading to higher sediment levels, but will be washed out to sea, so mudflats may tend to wash out (-ve) **Indirect impacts:** • Salt production will be less due to the increase in rainfall. (-ve)[5] • Agriculture productivity will be increasing as the monsoon helps the farmers as the majority of lands are under rain-fed irrigation. (+ve)[6] • Bird population would benefit through the increasing food from agriculture fields. (+ve)		
Decrease of rainfall during summer (Mar-May)	Decrease by 10.7% (i.e., -14.1mm, from 131.1 to 117.0 mm), during summer by 2050s.	**Low**[9]	**Medium**[10]	**Medium**	**Direct impacts:** • The mudflats will become less productive; Salinity will increase and the birds will not get sufficient food leading to fewer number visiting the area. (-ve) • Salt production increases as the conditions suitable for salt production; Some large waders will get food in saline ponds and salt pans (+ve) • Effluents from industrial salt pans increase the salinity and pollution; Feed for the birds reduced also the fish breeding and nursery grounds affected (-ve) • Increase in *Prosopis* extent will provide an increase in the nesting habitat of birds	**Medium**[13]	**Medium**

[5] This is the peak season for salt production, but flamingos will not be here during that season.
[6] Birds will benefit from increase in crops, but agricultural chemicals may affect the Ramsar site – enhancement of Agriculture and livelihoods could have negative impacts upon the Ramsar site. If livelihoods are improved the dependency upon the natural resources of the site will be decreased. Increased wealth would increase adaptive capacity of local community.
[9] Decrease is relatively small compared to natural baseline.
[10] Overall sensitivity is medium because the swamp is dominated by tidal exchange rather than rainfall.
[13] Adaptive capacity is medium – have capacity to deal with the pollution from salt pans but because of the size of the industry, it is difficult enforce.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
					Indirect impacts: • *Prosopis* extent will be increased due to drought and continuous fallow of the agriculture lands (slightly saline soils) in the TDEF areas. (-ve)[11] • Increase in *Prosopis* habitat would protect birds from predation. (+ve)[12]		
TEMPERATURE							
Increase of temperature during SW Monsoon (Jun-Sep)	For SW Monsoon, the average maximum temperature increase from 34.0 to 36.1ºC (increasing by 2.2ºC by 2050s).	High[14]	High[15]	High	**Direct impacts:** • Reduced breeding of fish and crustacea[16](-) **Indirect impacts:** • Reduction in fishery resources in the mudflats (-) • Increase the salt production in the area; The mudflats become less productive as the water salinity increases due to higher salt content in discharges (-)	Low[17]	High
Increase of temperature during NE Monsoon (Oct-Dec)	For NE Monsoon, the average maximum temperature increase from 29.7 to 31.6ºC (increasing by 1.9ºC by 2050s).	High	High	High	**Direct impacts:** • Increase the chances of cyclone due to the increase in atmospheric temperature (-) • Increased precipitation will lead to an increase in fishery productivity in the mudflats (+) • Food for avifauna increase (+) **Indirect impacts:** • Chances of cyclone increases (-)	Low	High

[11] The Department of Forests does have a program for Prosopis control - but very difficult to erradicate. The environmental conditions such as drought and highly heat tolerance slowly favoring the expansion into the sanctuary. Birds are nesting in Prosopis evnthough they are not much preferred species for nesting.
[12] Expansion of Prosopis creates challenges in terms of eradication of exotic invasive species. Dry conditions will encourage Prosopis which has some positive implications - but with potential serious long terms effects of the ecosystem.
[14] Increase in temperature likely to be moderated by increase in rainfall
[15] Water temperature in shallow areas will increase higher than atmospheric temp. increased evaporation leading to increased salinity
[16] This is the breeding season for fish and they prefer lower saline waters and lower water temperature at this time. For breeding of fish temp. and salinity may be pushed outside of comfort zone
[17] Natural systems of swamp have little capacity to adapt to increased temperatures

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase in temperature during summer (Mar-May)	By 2050s, hotter summer, average maximum temperature increase by 2.1ºCfrom 33.7to 35.8ºC.	High	Very High	Very High	**Direct impacts:** • Increase in soil and water salinity in the mudflats (-) • Evaporation of water increases the salinity; fishery resources affected; Food for birds getting reduced. **Indirect impacts:** • Fisher's livelihood is affected due to the lack of fish. (-) • Lack of tidal amplitude in the mudflat affecting fishing; fishers have to walk for long distances; boats won't sail due to less water; (-) • The mudflats have bivalves (oyster) beds; difficult for the fishers to walk along the mudflats; often get injured. (-)	Low	Very High
Increase of temperature during SW Monsoon (Jun-Sep)	For SW Monsoon, the average maximum temperature increase from 34.0 to 36.1ºC (increasing by 2.2ºC by 2050s).	Low[18]	Low	Low	**Direct impacts:** • Increase evaporation in the mudflats; less tidal water spread (-)	Low	Medium
EXTREME EVENTS							
Sea level rise	Very high risk of sea-level rise.	High	High	High	**Direct impacts:** • Loss of intertidal area due to permanent submergence and erosion (-) • Change in the ecosystem; seagrass beds may form; Loss of bird habitat; (-) • The wetlands of 441 and 875 ha are likely to be inundated due to rising sea levels at 0.5 and 1 m[19].	Low	High

[18] This is the cold winter and the increase of temperature does not have significant impacts on environmental conditions.
[19] State Government of Tamil Nadu, 2014. Tamil Nadu State Action Plan for Climate Change.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					• Out of the 348 ha of mangroves (Avicennia species), 14 and 65 ha will be under severe threat, resulting in a loss of 4.13 and 18.54% of mangroves. **Indirect impacts:** • Fishing will be reduced due to habitat loss (-) • Vulnerability of the area increased due to natural disasters like cyclones and coastal erosion (-)		
Cyclones	Very high risk of increased frequency of cyclones.	**Very High**	**Very High**	**Very High**	**Indirect impacts:** • Loss of mudflats due to erosion; saltwater flooding and deposition of marine sediments changes the topography; (-) • Damage to the ecosystem have an impact on fishers livelihood (-) • Bird feeding affected; Affect the migratory birds significantly; large scale mortality of birds witnessed during Gaja cyclone. (-) • The TDEF wildlife and bird population would be repressed due to the higher frequency of cyclones. **Indirect impacts:** • The saltwater intrusion will be high into the adjoining landward side (-) • Salinization of soil and water (-) • Damage to fishing boats and gear (-)	**Low**[20]	**Very High**
Storm surge	Low to moderate risk of up to 5 m storm surge	**Medium**	**Very High**	**High**	**Indirect impacts:** • Extensive water flooding over a period of time affects burrowing animals (-)	**Low**[20]	**High**

[20] Most of these wetlands are able to recover quickly from these events. Historically, there have been very few cyclones in this area, but they have been very damaging. With the projected increase in cyclones frequency, the capacity for recovery is reduced.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					• Modifies the topography and geomorphology of the coastal area (sand/sediment transport from the sea) affects the free flow of water; sedimentation of mudflats -> reduce swamp area (-) **Indirect impacts:** • Poverty levels will be increased; the migration of poor coastal communities to urban areas for their living. Women and single women will be more affected because they have less capacity to migrate out of swamp areas and to change their dependences on salt pans and fishing activities. (-) • Salinization of land and water affecting livelihood activities such as salt pan, fishing and aquaculture. (-)		

Photo credit: GIZ_Prasanth

Annex 2.3.1 – Scoring matrices

Sensitivity of system to climate threat	Exposure of system to climate threat: Very low	Low	Medium	High	Very High
Very High	Medium	Medium	High	Very High	Very High
High	Low	Medium	Medium	High	Very High
Medium	Low	Medium	Medium	High	Very High
Low	Low	Low	Medium	Medium	High
Very low	Very low	Low	Low	Medium	High

Figure 1 *Determining impact score from sensitivity and exposure*

Adaptive capacity	Impact: **Very low** Inconvenience (days)	**Low** Short disruption to system function (weeks)	**Medium** Medium term disruption to system function (months)	**High** Long term damage to system property or function (years)	**Very High** Loss of life, livelihood or system integrity
Very Low Very limited institutional capacity and no access to technical or financial resources	Medium	Medium	High	Very High	Very High
Low Limited institutional capacity and limited access to technical or financial resources	Low	Medium	Medium	High	Very High
Medium Growing institutional capacity and access to technical and financial resources	Low	Medium	Medium	High	Very High
High Sound institutional capacity and good access to technical and financial resources	Low	Low	Medium	Medium	High
Very High Exceptional institutional capacity and abundant access to technical or financial resources	Very low	Low	Low	Medium	High

Figure 2 *Determining the vulnerability score from Impact and Adaptive capacity*

9.3 ANNEX 3 - ADAPTATION PLANNING MATRICES

The matrices are attached as complementary materials.

***Table 21** Attached files of Adaptation Planning Matrices*

TARGET ASSET	ATTACHED FILE
Point Calimere Sanctuary	AAS2010-REP-002-03 Final Report Point Calimere (Annex 3.1 AP_Sanctuary).docx
Muthupet and Thalainayar mangroves	AAS2010-REP-002-03F Final Report Point Calimere (Annex 3.2 AP_Mangroves).docx
Great Vedaranyam Swamp	AAS2010-REP-002-03F Final Report Point Calimere (Annex 3.3 AP_Vedaranyam_Swamp).docx

Photo credit: GIZ_Prasanth

Annex 3.1 - Adaptation Planning Matrix for the Point Calimere Sanctuary

ASSET NAME: POINT CALIMERE SANCTUARY – TDEF FORESTS

ASSET DESCRIPTION: Point Calimere Wildlife sanctuary is one of the important habitats of the tropical dry-evergreen forest which has a cover of about 15 sq km. About 364 flowering plants have been identified in which *Manilkara hexandra (Palai* in Tamil) is the most important dominant dry evergreen tree species of the sanctuary. *Lannea coromandelica* which is an introduced species is the only deciduous species found in this forest. The sand-dunes are largely colonised by *Prosopis juliflora* and *Calotropis gigantea.* Spodic nesting of Olive Ridley turtles is noticed along the sandy beach. It is home to the largest population of the endemic Blackbuck *(Antilope cervicapra)* in south India. Other animals of the sanctuary include Spotted Deer *(Axis axis),* Wild Boar *(Sus scrofa)* and Jackal *(Canis aureus).* The Spotted Deer, feral-horse *(Equus caballus)* and the Bonnet Macaque *(Macaca radiate)* were introduced into the Sanctuary. Though agriculture and salt production are the main sources of livelihood around the Bird Sanctuary, cattle rearing also supports the livelihood of villagers during the lean period of farming. The people in villages nearby collect non-timber forest products from the sanctuary. These practices are now prohibited but not fully eliminated. They now mainly catch the fish and prawns in nearby saltpans and mudflats. The fruiting in *Manilkara hexandra* is varying to a greater extent. In few years the fruiting is very less which may be due to weather conditions. The population of *Antilope cervicapra* which was around 3000 earlier has come down to 1000. Due to better management practices, it has improved to 2000.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
Increase of temperature during SW Monsoon For SW Monsoon, the average maximum temperature increase from 34.0 to 36.1oC (increasing by 2.2oC by 2050s). (Jun-Sep) - **High**	• Increase in evaporation; Loss of water in the ponds and small streams affecting the fauna and flora (-) • Loss of grassland; Fodder scarcity; Competition for animals for grazing area; Crossing the sanctuary for fodder and water by the herbivores (-) • Loss of species diversity; sensitive species will be extinct; pollinators will be impacted leading to poor seed setting (-) **Indirect impacts:** • Reduction in forest produce (wild fruits such as *Manilkara* and spine guard) as the decrease in relative humidity and increase in temp affect productivity (-)	Planting of more trees along the water bodies to minimise evaporation and provide shelter/ fodder to wildlife including birds	Very High[1]	High	Very High
		Increase in watershed areas in elevated areas (contour bunds) to store more water and preventing water flow to the sea	High[2]	High	High
		Promotion of drought and saline tolerant species to meet the fodder demand for the herbivores	Very High[3]	Very High	Very High
		Planting of more trees along the water bodies to minimise evaporation and provide shelter/ fodder to wildlife including birds	High	High	High

[1] Most of the waterbodies are silted; It can be desilted and lined with polythene sheets to prevent seepage.

[2] Contour bunds can be prepared in the elevated areas which increases the water percolation and also increase the TDEF and grasslands.

[3] Some of the low lying are saline; Planting tolerant grass and other species will help the grazing animals to get adequate grass/fodder.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
Increase of temperature during the Summer (Mar-May) - By 2050s, hotter summer, average maximum temperature increase by 2.1ºC from 33.7 to 35.8ºC – **Very High**	• Increased evaporation of surface water leading to water scarcity for animals (-) • Less grassland productivity (-) and less area for grazing • Evapotranspiration leads to lesser photosynthetic efficiency (-) • Some tree species shed the leaves (some deciduous plants) to cope with the increase in temperature (-)	Enhancing the water storage capacity in the water bodies through desilting; Watersheds - cascade model by connecting different storage structures	Very High[1]	High	Very High
		Planting more trees along the water bodies to prevent evaporation	High	High	High
		Planting more drought-tolerant TDEF plants including grass species – eg. *Manilkara*	High	High	High
		Periodic removal of exotics like *Lantenna sp* and *Prosopis.*	Very High[4]	Very High	Very High
EXTREME EVENTS					
Sea-level Rise	• Loss of land area of sanctuary due to erosion in the eastern side (-) • Seawater intrusion and low lying areas flooded with saltwater and aquifer becomes saline (-) • Loss of vegetation due to increase in salinity (-) • Changes in species diversity[5](-) • Loss of habitat for sea turtle nesting (-)	Hard Engineering structures such as Physical Barrier: Sea wall; Groynes	High[6]	Low	Medium
		Planting shelterbelts (multiple species) to reduce coastal erosion	Medium	Medium	Medium
		Construction of weirs/sluice gates in the drains to prevent the entry of saline water into the PCWS.	Medium	High	High
		Planting sand binders and promoting natural vegetation in the open sand dunes to protect from wind erosion	High	High	High
		Planting native saline and drought-tolerant TDEFs	Very High[7]	Very High	Very High
Cyclones	• Loss of TDEF vegetation due to high wind velocity. Many trees will be uprooted; already the Gaja cyclone has been damaged extensively (Nov 2018); Wildlife (blackbuck; spotted	Hard Engineering structures such as Physical Barrier: Sea wall; Groynes; Encouraging sand-dune formation wherever possible	High[5]	Low	Medium
		Planting shelterbelt plantation to minimise the wind velocity in the seafront	Very High	Medium	High

[4] They invasive species occupies the TDEF and grasslands affecting

[5] Grassland areas affected by sea level leading to changes in species towards more saline tolerant plants, like salt marshes.

[6] The engineering structures are expensive and also difficult to maintain.

[7] The density of the plantation could be increased by planting suitable species in sparse areas to mitigate the impacts of cyclones.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
	deer and avifauna) severely affected. Many animals were washed from ashore near Nagapattinam and Vellankanni (-) • Erosion along the shore will be high; Loss of habitat for sea turtle nesting (-)	Veterinary care/shelter/preparedness to the wildlife during and after the disasters	Medium	High	High
		Increasing the density of TDEF to reduce the wind speed; Large areas of blanks can be planted with tree species	Very High[6]	Very High	Very High
Storm Surges	• Uprooting of vegetation due to storm surge, an increase of salt in the soils around the forest and grasslands, infiltration of storm surge water will affect groundwater (-) • Extensive water flooding over a period of time affects the vegetation in the PC sanctuary (-) • Large areas become saline. • Modifies the topography and geomorphology of the area (sand/ sediment transport from the sea) casting over the area affects the soil conditions; siltation of canals and drains (-)	Hard Engineering structures such as Physical Barrier: Sea wall; Groynes; Encouraging sand-dune formation wherever possible	High[5]	Low	Medium
		Identifying the low lying areas and preparing drainage systems to drain water quickly	Medium	High	High
		Planting dense tree cover on the seafront minimise the wind and surge velocity	Medium	High	High

Annex 3.1.1 - Scoring of feasibility and effectiveness for prioritising adaptation options

		Effectiveness in dealing with impact				
		Very low	Low	Medium	High	Very High
Feasibility of action	Very High	Medium	Medium	High	Very High	Very High
	High	Low	Medium	Medium	High	Very High
	Medium	Low	Medium	Medium	High	Very High
	Low	Low	Low	Medium	Medium	High
	Very low	Very low	Low	Low	Medium	High

Photo credit: GIZ_Prasanth

Annex 3.2 - Adaptation Planning Matrix for Mangroves

ASSET NAME: MANGROVES (MUTHUPET AND THALINAYAR)

ASSET DESCRIPTION: The Muthupet mangrove wetland is located in the southern most end of the Cauvery delta in Thanjavur and Thiruvarur districts (10º18′ to 10º22′ N latitude and 79º28′ to 79º36′ E longitude). It occupies an area of approximately 12,000 ha, including a 1,700 ha lagoon. The mangrove vegetation is only in a small area of about 1,500 ha. The remaining areas are mostly degraded mudflats. The wetland consists of seven reserve forests namely Palanijur RF, Thamarankottai RF, Maravakkadu RF, Thurukkadau RF, Thambikottai RF, Vadakadu RF and Muthupet RF. *Avicennia marina* is an abundant species followed by Excoecaria agallocha, Aegiceras corniculatum, Lumnitzera racemosa, Acanthus *ilicifolius, Ceriops decandra, Rhizophora apiculata* and *Rhizophora mucronata.* The halophytes namely *Suaeda maritima* and *S. monoica* are also available in the wetland. Canal fishing, the traditional fishing method is being practiced in Vedaranyam. People belonging to 26 coastal hamlets of Vedaranyam with a total population of about 35,900 depending on the fishery and forestry resources of Muthupet.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
Sea level rise - **High** The wetlands of 441 and 875 ha are likely to be inundated due to rising sea levels at 0.5 and 1 m[1]. Out of the 348 ha of mangroves (Avicennia species), 14 and 65 ha will be under severe threat, resulting in a loss of 4.13 and 18.54% of mangroves.	• Loss of mangrove extent due to submergence. Lesser possibility of the vertical elevation of the mangrove floor (substratum) due to less sediment flow (-). • Movement of mangroves into the elevated areas – mostly Prosopis and halophyte dominant in the fringes (-) • Salinization of the area increased due to seawater inundation and intrusion (-) • Tend to move landward side due to shift in the high tide area; However, the landward movement is not possible because of the land use by the private landholdings which is used for salt pan, agriculture or aquaculture (-)	Assessment of SLR through various models for Muthupet mangroves; Increasing freshwater supply bring sediments that enable vertical growth of floor to minimise the inundation.	**Low[2]**	**High[3]**	**Medium**

[1] State Government of Tamil Nadu, 2014. Tamil Nadu State Action Plan for Climate Change.
[2] The Cauvery River water flow is very minimum and it flows very rarely during monsoon. River water is dammed and fully exploited. There is very less possibility to enhance the water quantum
[3] The fresh water flow is very vital for the mangroves as it brings down the soil salinity as well as it brings sediments which will settle and the floor level increase.

Annex 3.2.1 - Scoring of feasibility and effectiveness for prioritising adaptation options

		Effectiveness in dealing with impact				
		Very low	**Low**	**Medium**	**High**	**Very High**
Feasibility of action	**Very High**	Medium	Medium	High	Very High	Very High
	High	Low	Medium	Medium	High	Very High
	Medium	Low	Medium	Medium	High	Very High
	Low	Low	Low	Medium	Medium	High
	Very low	Very low	Low	Low	Medium	High

Photo credit: WISA (Harsh)

Annex 3.3 - Adaptation Planning Matrix for the Great Vedaranyam Swamp

ASSET NAME: GREAT VEDARANYAM SWAMP

ASSET DESCRIPTION: The Great Vedaranyam Swamp (GVS), which includes the Panchanathikulam wetland area and an un-surveyed Salt Swamp area, has a long history of salt production. Many domestic and industrial salt works operate in the GVS. There was a great change in land use cover after Tsunami as the salinity levels of groundwater increased. People have completely stopped farming activities because of seawater intrusion into farmlands after the tsunami. The impacts of salt works will alter the ecosystem, affecting the flora and fauna of the GVS, besides having possible repercussions on the fisheries of the coast. The flow of fresh water from the River Cauvery is now very less affecting the biodiversity in and around the GVS. The Great Vedaranyam Swamp serves as the spawning and nursing ground for commercially important maritime prawns and fishes, such as *Penaeus indicus, P. monodon, Hilsa ilisha* and *Chanos chanos.* Other than these fishes the swamp has a large population of mullet and exotic *Oreochromis mossambicus (Tilapia mosambica).* Mud crab *Scylla serrata* is a commercially important species from the Swamp. The coast of Point Calimere is an important fish landing site for fishes and prawns from November to February. Both species of flamingos viz., the Greater Flamingo *Phoenicopterus roseus* and Lesser Flamingo *P. minor* inhabit the Great Vedaranyam Swamp. In the 1980s, the Point Calimere supported >10,000 Lesser Sand Plover, >15,000 Black-winged Stilt, >50,000 Black-tailed Godwit, >200,000 Little Stint and >150,000 Curlew Sandpipers (Balachandran 2006[1]), but these have come down <500 between 2007 and 2010 (Mankanndan et al 2011[2]). Compared to previous reports from Tamil Nadu Forest Department Census Records (unpublished data), the abundance of many waterbird species are now becoming very rare and uncommon and declining year after year. In 2002, the Point Calimere coastal area, comprising 38,500 hectares, was declared a Ramsar site (No.1210) and a place of international importance for the conservation of wetland.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
Increase of temperature during SW Monsoon For SW Monsoon, the average maximum temperature increase from 34.0 to 36.1ºC (increasing by 2.2ºC by 2050s). (Jun-Sep) - **High**	• A decrease in fishery resources affects the food chain for avifauna. • Salinization of the area due to evaporation	Facilitating tidal water flow into the swamp area to decrease the salinity and enhance the productivity by desilting canals especially in the mouths through desilting of drains	Medium	Medium	Medium
		Practicing sustainable fishery – Preventing collection of juvenile fishes and fishing ban in peak bird migratory season	Low	Low	Low
Increase of temperature during NE Monsoon (Oct-Dec) For NE Monsoon, the average maximum temperature increase from 29.7 to 31.6ºC (increasing by 1.9ºC by 2050s) - **High**	• Salinization of the area due to evaporation	Facilitating tidal water flow into the swamp area to decrease the salinity by desilting canals especially in the mouths	Medium	Medium	Medium

[1] Balachandran S. 2006. The decline in wader populations along the east coast of India with special reference to Point Calimere, south-east India. In: Water birds around the World. Boere, G.C., C.A. Galbraith & D.A. Stroud (Eds.). The Stationery Office, Edinburgh, UK. pp. 296–301.
[2] Manikannan R, Asokan S Mohamed Samsoor Ali A and Madhuramozhi G. (2011). Status, abundance and threats to waterbirds of the Great Vedaranyam Swamp, Point Calimere Wildlife Sanctuary (Ramsar Site), South-east coast of India. Journal of Research in Biology 2: 93-100

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
Increase of temperature during the Summer (Mar-May) - By 2050s, hotter summer, average maximum temperature increase by 2.1°C from 33.7 to 35.8°C. – **Very High**	• An increase in salinity affects the bird communities • Reduction in fishery resources affect avifauna and livelihood of fishers • Infestation of barnacles	Desilting of canals for free flow of tidal water to reduce salinity	High[3]	Medium	Medium
		Planting more TDEF and other vegetation along the fringes of the swamp to reduce the water loss and safe habitat for fauna	High[4]	Medium	Medium
EXTREME EVENTS					
Sea-level Rise	• Erosion and submergence of the swamp area. • Altering in Biodiversity	Hard Engineering structures such as Physical Barrier: Sea wall; Groynes	High[5]	Medium	High
		Beach nourishment; Creating sand-dunes along the fringes to reduce erosion	Medium	Medium	Medium
		Planting halophytes and other vegetation	Medium	Medium	Medium
Cyclones	• Erosion, water flooding, deposition of marine sediments	Hard Engineering structures such as Physical Barrier: Sea wall; Groynes.	Medium	Medium	Medium
		Planting halophytes and other coastal vegetation along the fringes to prevent the impact of cyclones on the mudflat.	Medium	Medium	Medium
Storm surges	• Change in the topography and geomorphology; flooding	Hard Engineering structures such as Physical Barrier: Sea wall; Groynes.	Medium	Medium	Medium
		Planting halophytes; mangroves, TDEF wherever possible to reduce the impact.	Medium	Medium	Medium

[3] The tidal water flow will reduce the soil temperature during hightides.
[4] The shade by the TDEG/other vegetation in the fringes provide shelter to avifauna; reducing the temperature.
[5] It is expensive and difficult to maintain.

Annex 3.3.1 - Scoring of feasibility and effectiveness for prioritising adaptation options

		Effectiveness in dealing with impact				
Feasibility of action		**Very low**	**Low**	**Medium**	**High**	**Very High**
	Very High	Medium	Medium	High	Very High	Very High
	High	Low	Medium	Medium	High	Very High
	Medium	Low	Medium	Medium	High	Very High
	Low	Low	Low	Medium	Medium	High
	Very low	Very low	Low	Low	Medium	High

Photo credit: GIZ_Neha

Photo credit: GIZ_Prasanth

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