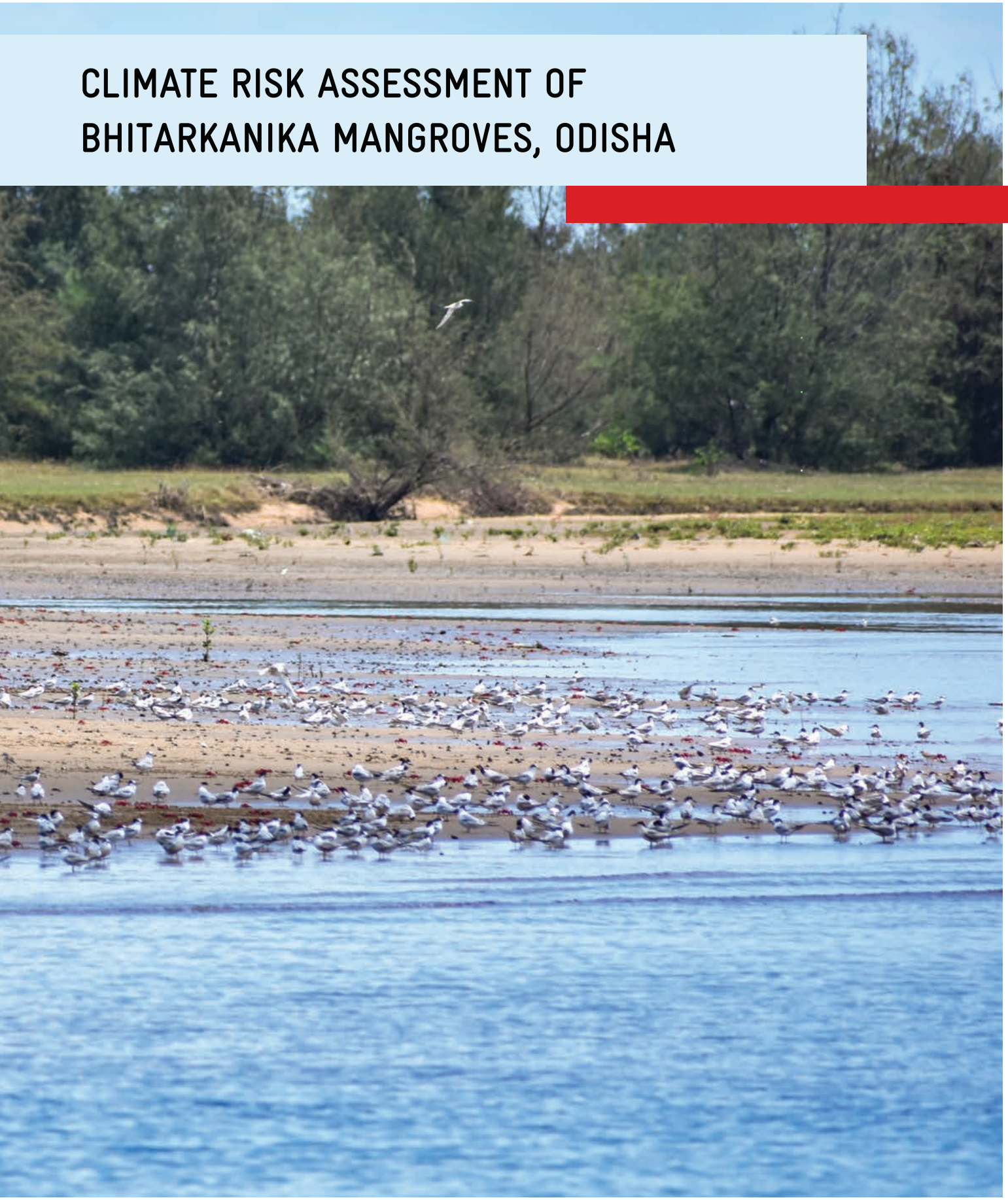
CLIMATE RISK ASSESSMENT OF BHITARKANIKA MANGROVES, ODISHA



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New Delhi, 2023

CLIMATE RISK ASSESSMENT OF BHITARKANIKA MANGROVES, ODISHA

DEVELOPMENT OPTION SYSTEM

icem
Climate Change | Biodiversity
Water | Integrated Assessments

MSSRF
Science for Sustainable Development

ABBREVIATIONS AND ACRONYMS

ACF	ASSISTANT CONSERVATOR FOREST
A&FE	DEPARTMENT OF AGRICULTURE AND FARMERS' EMPOWERMENT
ACF	ASSISTANT CONSERVATOR FOREST
ADB	ASIAN DEVELOPMENT BANK
BICAT	BASIN WISE INTEGRATED CATCHMENT AREA TREATMENT
CABI	CENTRE FOR AGRICULTURE AND BIOSCIENCE INTERNATIONAL
CAM	CLIMATE CHANGE ADAPTATION AND MITIGATION
CDA	CHILIKA DEVELOPMENT AUTHORITY
CHL	LEAF CHLOROPHYLL
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
CSOS	CIVIL SOCIETY ORGANISATIONS
CWC	CENTRAL WATER COMMISSION
DEST	DEPARTMENT OF ENVIRONMENT AND TECHNOLOGY
DFO	DIVISIONAL FOREST OFFICE
DFS-GOPA	DAIMLER FINANCIAL SERVICES INDIA PVT. LTD. – GOPA
DRM	DISASTER RISK ASSESSMENT
EDCS	ECO-DEVELOPMENT COMMITTEES
ESZS	ECO-SENSITIVE ZONES
FAO	FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
FARDD	FISHERIES AND ANIMAL RESOURCES DEVELOPMENT DEPARTMENT
FECCD	FOREST, ENVIRONMENT AND CLIMATE CHANGE DEPARTMENT
FGDS	FOCUS GROUP DISCUSSIONS
FH & FLCS	FISH HARBOURS AND FISH LANDING CENTRES
FPOS	FARMER PRODUCER ORGANISATIONS
GDD	GROWING DEGREE DAYS
GENS	THE GLOBAL ENVIRONMENTAL STRATIFICATION
GIS	GEOGRAPHIC INFORMATION SYSTEM
GIZ	DEUTSCHE GESELLSCHAFT FÜR INTERNATIONALE ZUSAMMENARBEIT GMBH
GPP	GROSS PRIMARY PRODUCTION
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
IEC	INFORMATION, EDUCATION AND COMMUNICATION
IM	IMMEDIATE
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
LAI	LEAF AREA INDEX
LT	LONG TERM
LULC	LAND USE AND LAND COVER
MoEFCC	MINISTRY OF ENVIRONMENT, FOREST AND CLIMATE CHANGE
MoU	MEMORANDUM OF UNDERSTANDING
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
NTFPS	NON-TIMBER FOREST PRODUCTS
OSPCB	ODISHA STATE POLLUTION CONTROL BOARD
OTDC	ODISHA TOURISM DEVELOPMENT CORPORATION LTD.
P&C	PLANNING & CONVERGENCE DEPARTMENT, GOVERNMENT OF ODISHA
PMSBY	PRIME MINISTER SURAKHYA BIMA YOJANA
PPP	PUBLIC–PRIVATE PARTNERSHIP
PRDWD	PANCHAYATI RAJ AND DRINKING WATER DEPARTMENT
PRECIS	PROVIDING REGIONAL CLIMATES FOR IMPACTS STUDIES
R&DM	REVENUE AND DISASTER MANAGEMENT
RAINFOREST CRC	COOPERATIVE RESEARCH CENTRE FOR TROPICAL RAINFOREST ECOLOGY AND MANAGEMENT
RCDC	REGIONAL CENTRE FOR DEVELOPMENT COOPERATION
RCP	REPRESENTATIVE CONCENTRATION PATHWAY
RD	RURAL DEVELOPMENT
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
ST	SHORT TERM
THI	TEMPERATURE HUMIDITY INDEX
TN-ICPP	TAMIL NADU – INTEGRATED COASTAL PROTECTION PLAN
UK	UNITED KINGDOM
UN	UNITED NATIONS
VHF	VERY HIGH FREQUENCY
WBCIS	WEATHER-BASED CROP INSURANCE SCHEME
WIAMS	WETLAND INVENTORY, ASSESSMENT AND MONITORING SYSTEM
WRD	WATER RESOURCES DEPARTMENT
WRTC	WETLAND RESEARCH AND TRAINING CENTRE
ZSI	ZOOLOGICAL SURVEY OF INDIA

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Photo credit: GIZ APOWA

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Acknowledgements

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Summary

Wetland ecosystems 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 frequency and severity of extreme events, including floods, droughts and storms. A strong knowledge base of climate change risks is therefore essential for Ramsar site managers for prioritising and planning appropriate adaptation and mitigation actions. This report presents a climate change vulnerability assessment and adaptation plan for the Bhitarkanika Mangroves Ramsar site. The aim is to have the results of this technical and consultative process integrated into the overall site management plan to enhance ecosystem resilience through effective adaptation to climate change.

BHITARKANIKA MANGROVES RAMSAR SITE

The Bhitarkanika Mangroves, located in Odisha State, India, cover about 65,000 ha and were designated as a Ramsar Site in 2002. It had been declared as the Bhitarkanika Wildlife Sanctuary back in 1975 under the National Wildlife Protection Act, with a core area of 14,500 ha designated as Bhitarkanika National Park for stricter conservation management under the Wildlife Protection Act.

This sanctuary is one of the finest remaining patches of mangrove forest along the Indian coast. The site is visited by about 500,000 Olive Ridley Turtles annually, making it the world's largest mass nesting beach. It is also a habitat of international importance for bird nesting and breeding – 280 species of birds have been identified, and the site contains one of the largest heronries in Asia. The Bhitarkanika Mangroves have the highest density of Saltwater Crocodiles *(Crocodylus porosus)* in the country, with a population of nearly 1700 individuals. It is one of the most diverse mangrove ecosystems in India, with 70 mangrove species. That dense mangrove forest protects local villages from devastating cyclones and tidal surges. Villages with wider stretches of the Bhitarkanika Mangroves between them and the coast experienced significantly fewer deaths compared to ones with narrower or no mangroves[1]. The area also supports 2,50,000 inhabitants in 410 villages whose livelihood is mainly dependent on agriculture, fishing and aquaculture.

METHODOLOGY FOR THE CLIMATE VULNERABILITY ASSESSMENT AT THE BHITARKANIKA MANGROVES RAMSAR SITE

The climate vulnerability assessment at the Bhitarkanika Mangroves 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 planning and implementation. In this case, it was tailored for use at Ramsar sites. It is a robust framework for systematically identifying climate change risks, their impacts and adaptation responses. The CAM method combines a range of supporting tools that are based on international best practices. The intention is to have the vulnerability assessment and adaptation planning process integrated into the regular Ramsar site management planning cycle.

The CAM method has three main phases: (I) impact and vulnerability assessment; (II) adaptation planning; and (III) adaptation implementation and feedback. The GIZ and ICEM team worked with site managers and local stakeholders to apply the CAM method 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 (exposure, sensitivity, impact and adaptive capacity) based on an understanding of the threats posed by climate change.

BASELINE CONDITIONS AT THE BHITARKANIKA MANGROVES RAMSAR SITE

The target assets selected for this vulnerability assessment include the large catchment areas of the Brahmani and Baitarani rivers, which flow into the Ramsar site, and the mangrove habitats that characterise the site. The key species assets identified for the vulnerability assessment include the Saltwater Crocodile and the Olive Ridley Turtles, which nest along the Gahirmatha beach. The target ecosystem services, and livelihoods assets include fisheries and tourism.

The catchment covers an area of nearly 52,000 km^2, with 52% agricultural land and 34% forest cover. There are several irrigation and hydropower dams within the catchment, including the Rengali Dam, which controls the flow of freshwater downstream, in addition the offtake of water for irrigation and the domestic water supply within the

[1] For example, Saudamini Das and Jeffrey R. Vincent, 2009, Mangroves protected villages and reduced death toll during Indian super cyclone, PNAS May 5, 2009 106 (18) 7357–7360, https://www.pnas.org/content/106/18/7357

water for irrigation and the domestic water supply within the vicinity of the mangrove area. Developments in the catchment have increased soil erosion and sediment transport down the rivers, and large industries, including those associated with aluminum and fertilisers, a thermal power station on the Brahmani river and agricultural runoff in the catchment are also causing pollution of the mangrove creeks.

The species diversity of the mangrove forest at Bhitarkanika is one of the greatest in India, with 55 of the 58 Indian mangrove species and 3 endemic species being recorded there, reflecting the diversity of micro-habitats and conditions at the site. The extent of the mangrove forest has been increasing due to replanting initiatives by the Forest Department, but the mangrove species mix has been changing due to the increasing salinity in the area. In particular, the decrease in Hental *(Phoenix paludosa)* is a cause for concern because it provides an important habitat constituent for the Saltwater Crocodiles. It is estimated that nearly 1700 individuals are living at the Ramsar site. The Saltwater Crocodile is a keystone species in the area, and its numbers are increasing due to protection afforded by the Forest Department – the site is closed to tourists during the nesting season, between May and July, each year.

Gahirmatha Beach is the largest nesting ground of the Olive Ridley Sea Turtle *(Lepidochelys olivacea)* in the world, with up to 450,000 turtles visiting the site in a year. Already, beach erosion is taking place at the Bhitarkanika Ramsar site, and there are instances of failure of the mass nesting due to drastic changes in the characteristics of the nesting beach, e.g., brought about by cyclones. The mass nesting now takes place along a 900 m long beach of Dr. Abdul Kalam Island (formerly Wheeler Island). Increasing temperatures may also deter Olive Ridley Turtles from nesting at Gahirmatha.

The ecosystem services provided by the Ramsar site and the livelihoods of the local communities include tourism, which is increasing, with 20 – 25 villages close to the sanctuary providing hospitality services, boats and guides for the tourists. About 50,000 visitors come to Bhitarkanika each year between January and April and between August and December.

The ecosystem services provided by the Ramsar site and the livelihoods of the local communities include tourism, which is increasing, with 20 – 25 villages close to the sanctuary providing hospitality services, boats and guides for the tourists. About 50,000 visitors come to Bhitarkanika each year between January and April and between August and December.

Fishing is an important livelihood activity within the creeks and offshore, the activity in both areas depending on the nursery grounds provided by the mangroves. Over the past 10 years, the annual marine fish catch has doubled to nearly 10,000 MT at eight landing sites around the Ramsar site. However, increasing salinity in the creeks and pollution, as well as overfishing, have reduced catches of some species such as Telia and Chandi. Some species have vanished from the catch, while others such as the Hilsa have reduced in fish size. Meanwhile, brackish water aquaculture for prawns is increasing the conversion of paddy fields to fishponds, promoted by the Fisheries Department.

CLIMATE CHANGE AT THE BHITARKANIKA MANGROVES RAMSAR SITE

Projections of the precipitation and temperature by the 2050s at the Bhitarkanika Mangroves were generated, with respect to a baseline period of 1960 – 1990, using an ensemble mean of three selected GCMs – CCSM4, HadGEM2-ES and MIROC-ESM and applying the RCP 8.5 scenario.

Precipitation

The total rainfall is projected to increase by 3.9%, or 48.3 mm, from 1262.2 mm to 1310.4 mm, during the monsoon (June - October). The increase will be more significant for areas immediately upstream (by 11.2%, or 140 mm) of the catchment.

By the 2050s, the precipitation in summer (February – May) is projected to decrease by 13.7 mm, or 8.2%, from 167.0 mm to 153.7 mm. A slight decrease of 3.7 mm (5.5%) is also projected for winter (November – January). Decreases in rainfall will be more significant in the mangrove forests compared with areas upstream of the catchment.

Temperature

Summer in the 2050s will be warmer, with the average maximum temperature is projected to increase by 2.1°C (from 33.5°C to 35.6°C). Summer will be an extreme season, with limited rainfall and higher temperatures, which will stress the forests and associated species.

The average maximum temperature during the monsoon season is projected to increase from 31.6°C to 33.5°C (+1.9°C). Winters are projected to be warmer, with a 2.0°C increase in the average maximum temperature (from 27.6°C to 29.6°C), by the 2050s. That increase is projected to be more significant for areas immediately upstream of the catchment.

Extreme events

With climate change, extreme cyclones and storm surges are expected to increase in frequency and intensity along the Odisha coast. Bhitarkanika has a 'very high' risk of an increased frequency of cyclones and a 'moderate' to 'high' risk of storm surges of up to 5 m. Climate change is also expected to bring heavy, intense and unexpected rainfall, which will cause flooding of low-lying areas.

The rising sea-level is one of the most important consequences 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 reference, averaged over a period such as a month or a year, i.e., a period that is sufficiently long that fluctuations caused by waves and tides are largely removed. The sea level rise is projected to be 0.5 m by the 2040s at the Ramsar site coastline, according to the Central Water Commission (CWC).

IMPACT AND VULNERABILITY ASSESSMENTS

The Bhitarkanika Ramsar site has a 'high' vulnerability to the projected climate changes, like the sea-level rise and the increase in the frequency of cyclones. Furthermore, the vulnerability of mangroves to both the decrease in rainfall during the dry season (February – March) and the increase in temperature during the monsoon and summer periods is 'very high'. Since mangroves provide habitats for crocodiles and fish and support tourism, their vulnerability will have knock-on impacts on the dependent crocodiles and fish as well as many other wildlife assets such as migratory birds.

Saltwater Crocodiles are ectotherms, meaning their body temperature is closely tied to environmental temperatures. To avoid the predators, juvenile crocodiles dive underwater and hide for long periods of time. According to a recent study, this 'predator avoidance dive' will be affected by rising water temperatures, which make it difficult for crocodiles to remain submerged for long periods of time[2].

Also, the sea-level rise and storm surges are likely to degrade and reduce their habitat.

Olive Ridley Sea Turtles are highly vulnerable to the sea-level rise, to cyclones and to storm surges, which degrade and reduce their habitat. Overall, the fisheries are highly vulnerable to all extreme events at Bhitarkanika and to the projected decrease in rainfall during the dry season and increase in temperature in winter (November – January).

Tourists visit the site at their convenience and inclination. The number of visitors will be highly vulnerable to extreme events such as cyclones and storm surges and to loss of habitat to the sea-level rise.

The catchment area of the Ramsar site is very large and extends several hundreds of kilometers inland from the sea. The vulnerability of the catchment area to the decrease in rainfall during the dry season and the increase in temperature during summer and winter is 'high'. The catchment is also vulnerable to an increase in the frequency of cyclones, which cause excess rainfall and flooding.

The adaptive capacity of biological assets such as mangroves, crocodiles, fisheries and sea turtles is mostly low to all the extreme events – such as the sea-level rise, cyclones and storm surges, although crocodiles are quite resilient to cyclones. The fisheries have limited capacity to adapt to decreases in rainfall during the dry season, and tourism is unable to adapt to the sea-level rise and more frequent cyclones. The catchment generally will not respond well to increases in temperature during winter (November – January) as there will be an increased demand for water for ecosystem services. Nor will it readily adapt to more frequent occurrences of cyclones that cause flooding.

[2] Angela Heathcote, 2017, Climate change to affect crocodile population size, Australian Geographic, October 5, 2017.

Summary vulnerability scores for Bhitarkanika Mangroves

Threats	Mangrove habitat					Saltwater Crocodile					Catchment					Fisheries					Gahirmatha – Olive Ridley Sea Turtles					Tourism				
	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul
Precipitation																														
Increase of rainfall during Monsoon (Jun–Oct)	H	M	H	H	M	H	L	M	VH	M	H	M	H	H	M	L	L	L	VH	L	VL	VL	VL	VH	VL	M	M	M	VH	L
Decrease of rainfall during dry season (Feb-May)	VH	H	VH	M	VH	M	M	M	M	M	H	H	H	M	H	H	H	H	L	H	L	M	M	L	M	VL	VL	VL	VH	VL
Temperature																														
Increase of temperature during the Monsoon (Jun–Oct)	H	M	H	M	H	M	H	H	H	M	M	H	M	M	M	L	M	M	M	M						VL	VL	VL	VH	VL
Increase in temperature during summer/pre-monsoon (Feb-May)	H	H	H	M	H	VH	H	VH	M	VH	H	H	H	M	H	M	H	M	M	M	M	H	H	M	H	M	M	M	H	M
Increase of temperature during the winter (Nov–Jan)	M	M	M	M	M	VL	VL	VL	H	VL	M	M	M	L	H	H	H	H	M	H	L	H	M	M	M	VL	VL	VL	VH	VL
Extreme events																														
Sea level rise	VH	VH	VH	L	VH	VH	H	VH	L	VH						M	M	M	L	H	VH	VH	VH	VL	VH	VH	H	VH	L	VH
Cyclones	VH	VH	VH	L	VH	VH	L	H	H	M	H	H	H	L	H	H	M	H	L	H	VH	VH	VH	VL	VH	VH	H	VH	L	VH
Storm surge	H	H	H	L	H	H	VH	VH	VL	VH						M	M	M	L	H	H	H	H	L	H	H	H	H	M	VH

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

ADAPTATION PLANS

A range of adaptation measures need to be carried out with due care and attention. Salinity increases are to be addressed by maintaining the freshwater flow from the catchment and establishing rainwater storage for groundwater recharge within the mangrove area. The health of the mangroves will be supported by desilting the creeks to facilitate tidal exchange. Mangrove replanting has long been an important management strategy. It needs to be continued to fill gaps caused by cyclones and to afforest blank areas that will become suitable for mangroves as the sea level rises. Pollution from the catchment is a continuing concern. Wastewater and solid waste treatment in the catchment will become more important with climate change to reduce the stresses of poor water quality in the creeks. Specific adaptation measures will be required to keep the nesting habitats and beaches of the key species (the Saltwater Crocodiles and the Olive Ridley Turtle) cool in the face of increasing temperatures. Even using artificial incubation and hatching techniques may be required.

RECOMMENDATIONS FOR THE MANAGEMENT OF THE SITE AND STAKEHOLDERS

The feasibility and planning of the proposed adaptation measures will require appropriate surveys, research and design, followed by periodic monitoring to ensure their effectiveness. Implementing all or some of these measures will need the coordination and cooperation of the different stakeholders of the Bhitarkanika Ramsar site. There are several stakeholders, such as the Water Resources Department and Fisheries Department, with potentially conflicting development policies that will need to be resolved in order to implement the adaptation measures comprehensively. The creation of a coordination platform under the Forest, Environment and Climate Change Department with the assistance of the Odisha State Planning and Convergence Department is recommended to prioritise the measures that should be implemented over the next decade to protect the site against climate change.

1 INTRODUCTION

1.1 Background

Wetland systems are highly vulnerable to climate change. As climatic patterns become more extreme, wetlands will be affected through alterations in temperature, rainfall and hydrological regimes. A strong knowledge base of climate change risks is therefore essential for Ramsar site managers for prioritising and planning appropriate adaptation and mitigation actions.

ICEM has been commissioned by GIZ India to undertake 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 Lake, Pong Dam Reservoir, Bhitarkanika Mangroves and Point Calimere Wildlife and Bird Sanctuary. These four sites, namely an upland lake and a reservoir in Himachal Pradesh as well as two coastal mangrove areas in Odisha and Tamil Nadu, represent two very different sets of ecological and climate conditions.

The current management plans of these 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. A full understanding of the projected risks is essential if site managers are to prioritise and plan appropriate adaptation actions. This present assignment to work with site managers and local stakeholders to conduct climate change vulnerability assessments and adaptation planning aims to build a comprehensive adaptation strategy into the site management plans and budgets, which will lead to enhanced resilience of the four wetlands through more effective adaptive management. The assessments can also serve as demonstration of a methodology that can be replicated in other wetlands across India.

This Final Report on the climate risk assessment of the Bhitarkanika Mangroves Ramsar site is one of four linked reports on the four Ramsar sites. This report contains two chapters common to all the case study reports, which are followed by chapters with the findings specific to the Bhitarkanika Mangroves Ramsar site.

- **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 the Bhitarkanika Mangroves Ramsar site.
- **Chapter 3** provides the climate change profile for the site.
- **Chapter 4** synthesises and presents results from vulnerability assessments of the target assets, with the detailed VA matrices annexed.
- **Chapter 5** sets out the adaptation measures for the site from the adaptation matrices (annexed) covering 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 the management plans of the four Ramsar sites and to contribute to the objective 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 Lake, Pong Dam Reservoir, Bhitarkanika Mangroves and Point Calimere Wildlife and Bird Sanctuary.
- Proposing measures that help reduce the vulnerability of wetlands to climate change by mitigating the adverse changes, 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 plan for the region under the umbrella of the 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 capacities of stakeholders and decision makers to understand the climate risks and adaptation options.

1.3 Overview of the other three case study Ramsar sites

1.3.1 Renuka Lake

The Renuka wetland (77°27′E, 30°36′N) 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 above an adjoining pond, Parashuram Tal, which ultimately drains into the river Girl through a small channel. Lying in a narrow valley between two parallel steep hills, the lake is about five times as long as it is broad and has an area of approximately 30 ha. Its 500 ha catchment area includes about 250 ha of mostly sub-tropical deciduous forest of broad leaf tree species, bamboos, palms 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 the South-West monsoon through seasonal streams which also bring large quantities of silt and debris from poorly vegetated and degraded areas of the catchment. A perennial underground seepage water supply, possibly from the upper Giri river, has also been reported.

1.3.2 Pong Dam Reservoir

This reservoir (76°E, 32°N) drains a catchment area of 12,561 km^2, with 780 km^2 of permanent snow cover (Figure 1). The active storage capacity of the reservoir is 7290 Mm^3. The stored water is primarily used for meeting irrigation water demands. Nearly 7913 Mm^3 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 irrigation 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 the water inflow into the reservoir, apart from snow and glacier melt. The snow and glacier melt runoff in the Beas catchment was studied from 1990 to 2004 by Kumar et al. (2007) and its contribution is about 35% of the annual flow at Pandoh Dam (upstream of Pong Dam).

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

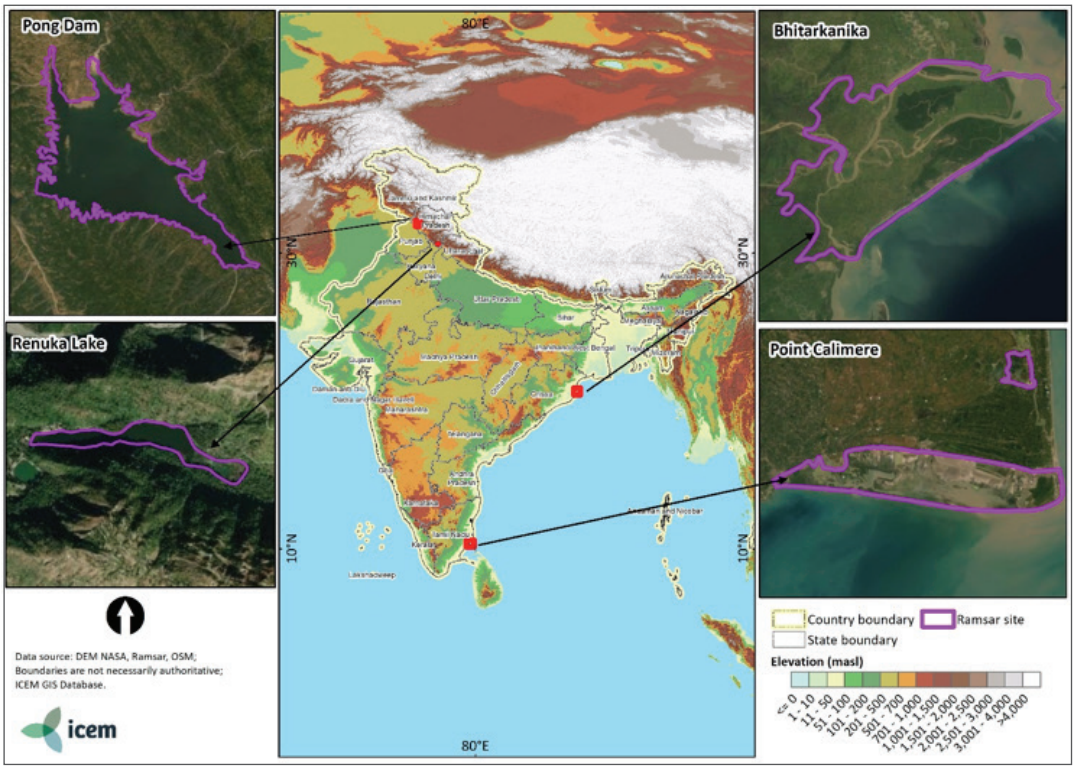

Figure 1 *Locations of the four Ramsar sites targeted for vulnerability assessment and adaptation planning*

1.3.3 Point Calimere Wildlife and Bird Sanctuary

Point Calimere Wildlife Sanctuary (10°18′N; 79°51′E), along with the Great Vedaranyam Swamp and the Thalainayar Reserved Forest, was designated as a Ramsar site in 2002. The total area of the Point Calimere Wetland Complex is 38,500 ha (Figure 1). The Point Calimere 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, including vulnerable waterbird species such as the Spoonbill Sandpiper *(Eurynorhynchus pygmaeus)* and Grey Pelican *(Pelecanus philippensis)*[3]. 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 livelihoods. A spread of *Prosopis,* salinisation of the groundwater and changes in the inflow of freshwater are all threats to the wetland habitats and species.

1.4 CAM process – Climate Change Adaptation and Mitigation

The overall process of this assessment followed the steps of the CAM (Climate Change Adaptation and Mitigation) method, which has been developed by ICEM as a flexible methodology for climate change adaptation and mitigation planning and implementation. It was adapted for Ramsar sites. 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, which must be integrated with development planning, in this case, the Ramsar site management plans.

[3] https://rsis.ramsar.org/ris/1210

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. Adaptation implementation and feedback

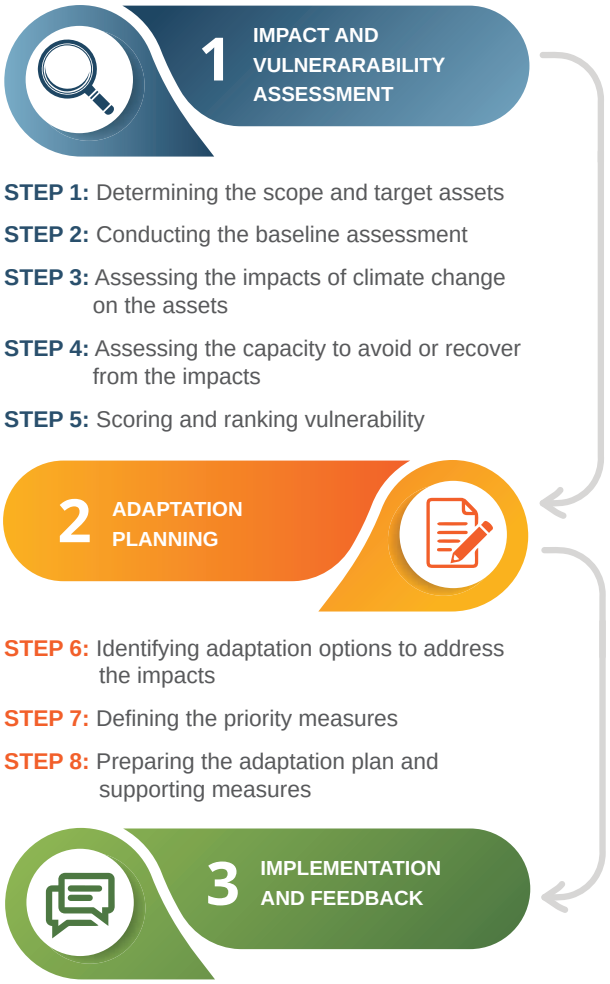

***Figure 2** Phases and steps of CAM*

For the vulnerability assessment and adaptation planning, the team used 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) based on 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. A companion volume to the four case studies *(Climate Change Vulnerability Assessment and Adaptation Methodology for Ramsar Sites in India – A Guide for Ramsar Site Managers)* provides detailed guidance to the CAM method and tools.

1.5 Stakeholder involvement and capacity building

Capacity building 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, in validating the assessments and exploring the adaptation options throughout the process.

This 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:

I. Developing the baseline and identifying the target assets for vulnerability assessment
II. Carrying out the vulnerability assessment to define the direct and indirect impacts
III. 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 virtual consultations. This process is summarised in Table 1.

Table 1 *Capacity building and institutional strengthening*

Activity	Description
Organising capacity building workshops and training programmes on climate risk assessment and adaptation for site managers, stakeholders and local organisations	Capacity building and increasing awareness about climate change risks and adaptation measures were included at the stakeholder consultation workshops where the vulnerability assessments and adaptation planning were presented and discussed. Consultation workshops were conducted during the field missions to the Ramsar sites and during the virtual consultation process.
Preparing a climate risk assessment framework and guidance document for wetlands that incorporates the learnings from the assessment.	Various documents will be prepared and published, including: • A CAM methodology guide for training and use at other Ramsar sites • A climate risk profile and vulnerability assessment of each of the four wetland sites • EbA action plan recommendations for each wetland site

2 BASELINE ASSESSMENT FOR BHITARKANIKA MANGROVES

2.1 Site description

The Bhitarkanika Mangroves (20°3′N, 86°54′E) located in Odisha, India, cover about 67,200 ha (Figure 3). It was designated a Ramsar Site in 2002. The area was declared as a wildlife sanctuary in 1975, and the core area of the sanctuary, with an area of 14,500 ha, was declared Bhitarkanika National Park in September 1998. Under the Wildlife Protection Act, development and livelihood activities are to be more strictly controlled in national parks than in sanctuaries.

The Bhitarkanika Wildlife Sanctuary is one of the finest remaining patches of mangrove forests along the Indian coast. As shown in the Figure 3, this site is visited by about 500,000 Olive Ridley Turtles, making it the world's largest mass nesting beach. A habitat for bird nesting and breeding, 280 species of bird have been recorded at the site, which contains one of the largest heronries in Asia. It has the highest density of Saltwater Crocodiles *(Crocodylus porosus)* in the country, with nearly 1700 individuals. It is one of the most diverse mangrove ecosystems in India, with 70 mangrove species. The mangrove forests provide vital protection for millions of people from devastating cyclones and tidal surges. Local communities have long depended on this ecosystem for food, medicines, tannins, fuelwood and construction materials, particularly honey and fish. Currently, the area also supports 250,000 inhabitants in 410 villages who are mainly dependent on agriculture, fishing and aquaculture. Additionally, the local people benefit from eco-tourism, which attracts over 60,000 tourists annually (Figure 3).

The main threat to this site is the reduction of freshwater flows as the water is mostly diverted for irrigation and other uses in the upper reaches of the catchment. Coastal erosion is prevalent due to the loss of mangroves and anthropogenic factors. Expansion of shrimp farms and interference of humans in the fragile ecosystem reduce habitats for wildlife. The Ministry of Environment, Forest and Climate Change (MoEFCC) has declared 192 villages around Bhitarkanika National Park as Eco-sensitive Zones (ESZs). The ESZ guideline prohibits shrimp farming within a 2 km radius of Bhitarkanika.

Figure 3 *Bhitarkanika Mangroves – Overview poster*
(Source: Indo-German Biodiversity Programme, Biodiversity conservation)

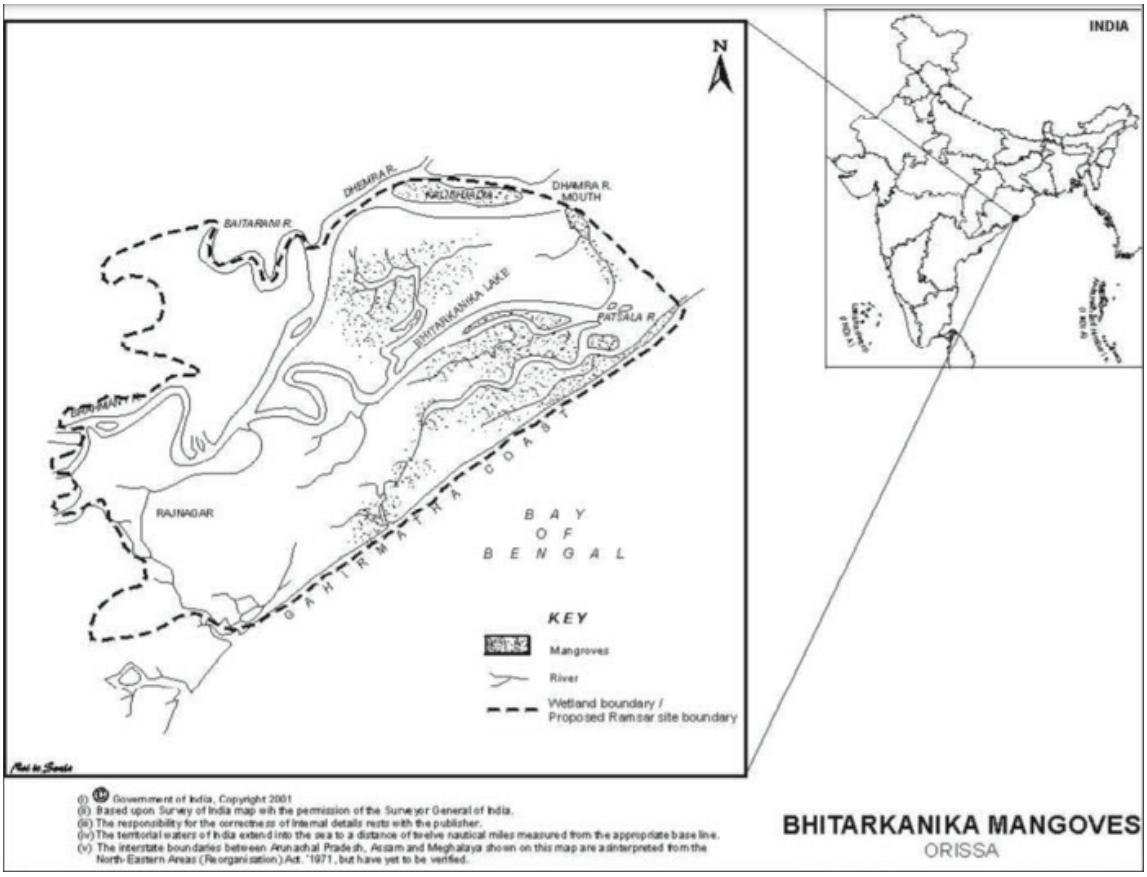

Figure 4 *Site map of Bhitarkanika Mangroves*
(Source: Government of India, 2001)

2.2 Identification of target assets

From the findings of the field missions to the site and the consultation with stakeholders, six target assets were selected for the vulnerability assessment. Two key habitats – the catchment of the Ramsar site and the mangrove forests – are priority assets, as are some keystone and vulnerable wetland species and ecosystem services (Table 2).

Table 2 *Selected target assets for Bhitarkanika Mangroves Ramsar site*

Target asset name		Description
Key habitats	Catchments	Brahmani and Baitarani rivers' catchments. This is a very large area containing multiple land uses and freshwater habitats.
	Mangrove habitats	29 true mangrove species and 72 mangrove associates from different mangrove forest sites of Bhitarkanika National Park
Keystone species	Saltwater Crocodiles	Bhitarkanika has the largest habitat of the endangered Saltwater Crocodile in India.
Wetland species important for Ramsar	Olive Ridley Turtles	The Olive Ridley Sea Turtle is an endangered species according to the IUCN Red List. The Gahirmatha coast is the site of the largest mass nesting in the world.
Ecosystem services/livelihoods	Fisheries	Fishing and aquaculture are the main livelihood activities of the people of the Ramsar site.
	Tourism and recreation	The national park is open for tourism from January to April and from August to December. The peak season for tourism is from October to February.

The six target assets were selected using a simple selection scoring method that complemented the overall vulnerability assessment of the site (Table 3).

Table 3 *Scoring for asset selections in Bhitarkanika (see Table 19 in Annex 1 on Methodology)*

Criterion	Question	Catchment	Mangrove habitat	Saltwater Crocodile	Olive Ridley Sea Turtle	Eco-services
Representativeness	To what extent is the habitat, species or ecosystem service representative of the site?	3	4[4]	5[5]	5[6]	4
Ecological significance	To what extent is the habitat, species or ecosystem service significant for ecological processes?	5	5[7]	5[8]	3[9]	4
Ramsar importance	To what extent is the habitat or species important for threatened or designated species?	4	3[10]	5[11]	5[12]	3
Sensitivity to change	To what extent has the habitat area/condition, species numbers or productivity of the ecosystem service varied over the past 20 years as conditions change?	4	2[13]	3[14]	4[15]	3
Non-climate threats	To what extent is the asset threatened by non-climate challenges or is the focus for management?	5	3[16]	2[17]	4[18]	4
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	4[19]	5[20]	4[21]	2
Total	**Sum the scores for each asset**	25	21	25	25	20

Scoring code: 1 Very Low 2 Low 3 Medium 4 High 5 Very High

[4] The mangrove forest's diversity of species and extent are crucial for the overall biodiversity and its conservation at the Bhitarkanika Ramsar site. Hental is one key species that is critical for nesting for birds. The deltaic region of Bhitarakanika is a unique bioclimatic zone for sustainable mangrove forests.
[5] Important species balances the ecosystem, at the top of the food chain.
[6] Gahirmatha beach, of Odisha, is largest mass nesting site of the Olive Ridley Turtle in India. Every year 3.5 to 4.5 lakhs Olive Ridley Turtles migrate to Gahirmatha for laying eggs.
[7] The mangrove forest is the habitat of all the wildlife in the site, including water birds, crocodiles and fishes. The mangroves protect local communities from natural disasters such as cyclones, storm surges and heavy winds.
[8] Their numbers control the diversity and numbers of all other species. The mangroves are protected indirectly as people do not venture into the forest because of the fear of crocodiles. The centre point of eco-tourism.
[9] Eats jelly fish and protects the sea-fish population.
[10] Important but not significant.
[11] Saltwater Crocodiles are important in maintaining the wetland ecosystem. There are around 1768 Gharial in Bhitarkanika.
[12] The Olive Ridley Sea Turtle is an endangered species according to the IUCN Red List.
[13] Sensitive to changes in salinity and to climate change.
[14] Crocodiles are adaptive to some of the projected changes such as increased rainfall and drought – but not to others such as the sea-level rise and cyclones.
[15] Sensitive to temperature, especially the number of eggs and the sex ratio of the offspring. Severe storms and the sea-level rise can destroy critical nesting beaches and damage nests.
[16] The anthropogenic threat is limited due to protection measures of the Forest Department.
[17] Crocodiles are protected well by the Forest Department.
[18] The mortality of Olive Ridley Turtles is increasing because of non-climatic threats such as marine fishing by trawlers using gill nets. In the last decade (2010 – 2020), the cumulative mortality was 9019 (data of Rajnagar Forest Division). In 2021, 800 died. Found on https://www.downtoearth.org.in/news/wildlife-biodiversity/at-least-800-olive-ridleys-dead-in-odisha-since-january-75383.
[19] Data are available on the extant and species diversity.
[20] Census data are collected by the Forest Department every year.
[21] Available census data of Forest Department.

2.2.1 The catchment

Bhitarkanika, covering an area of 51,822 km^2, receives freshwater inflows from the Brahmani and Baitarani rivers and their catchments. The river discharge is highest during the SW monsoon months (June – October). A major part of the catchment is agricultural land, accounting for 52.04%, with a cultivable area of about 3.2 Mha. The forest covers 34.4% of the catchment, 6.02% is wasteland, 4.62% is built-up land, and water bodies occupy 2.95%. The water bodies consist mainly of tanks (86%), with aquaculture ponds and saltpans in the coastal areas.

The catchments influence the wetland through large-scale effects on the hydrological regime, sediment delivery and chemistry. Assessments of key indicator parameters of the catchment are vital for understanding the status of Bhitarkanika and the pressures on it. Land-use changes can alter the hydrological regimes by affecting the rate and quantity of the water and nutrient fluxes.

The salinity at the Ramsar site has been increasing due to human activities such as (i) the construction of the Rengali Dam[22], which reduces the freshwater flow into the Brahmani river system, (ii) siltation of river mouths and creeks due to development activities in the catchment area and (iii) increased water consumption for irrigation, aquaculture, tourism and domestic supply. Salinity is the main cause of significant changes in the density and distribution of plants and key species, including mangroves, crocodiles, turtles and birds. The catchment is also the source of many pollutants from agricultural runoff and industrial effluents that are carried into the Ramsar site through the drainage system.

The extent of the paddy fields in the agricultural areas surrounding the mangroves around the Ramsar site has reduced significantly due to less freshwater inflow and the fields are increasingly replaced by aquaculture ponds. The water drawn from the wetland for aquaculture ponds and their polluted drainage water, cause significant changes and effects in the site, especially as the drainage water enters the wetland creeks and rivers.

2.2.2 Mangroves

Bhitarkanika has 300 plant species belonging to 80 families of mangrove and non-mangrove plants. It supports one of the largest mangrove plant diversities in India – 29 species of true mangrove and 72 mangrove associates have been recorded recently[23]. 55 of the 58 Indian mangrove species and 3 species of Sundari (*Heritiera* spp.), including *H. kanikensis,* are endemic species recorded at the site. The characteristic mangrove species include *Avicennia alba, A. officianalis, Rhizophora mucronata, Excoecaria agallocha, Acanthus ilicifolius, Sonneratia apetala* and *Heritiera minor.* Bhitarkanika presents a variety of habitats, micro-habitats and climatic conditions. Therefore, the diversity of the faunal component is extremely high in comparison with other mangrove forest areas of Odisha.

Nalia Grass (*Myriostachia wightiana),* found on the tidal banks, and the Bahumurga Climber (*Flagellaria indica),* found in the mangrove forest, are used for basket and rope making. The basket and rope making businesses have been reduced because of restrictions by the Forest Department in terms of access and exploitation. Presently four or five villages are continuing the basket making business. *Phoenix paludosa* is harvested for thatching purposes, and its use is restricted.

The extent of the mangrove forest has been increasing because of restoration and management activities by the Forest Department, but the locations of the mangrove species and composition have changed because of higher salinity levels. The decrease of Hental *(Phoenix paludosa)* is a concern as it is the main habitat of crocodiles and other animals.

The rich green mangrove forest in the estuaries of the Brahmani, Baitarani, Dharma and Mahanadi rivers is the main habitat of the Saltwater Crocodile. The mangroves and their associated vegetation provide an excellent habitat for the population of Saltwater Crocodiles. The mangrove ecosystem plays a vital role in the food web in general and contributes to the detritus food chain in particular. This dynamic ecosystem supports a very rich diversity of estuarine species of plants and animals. The abundant herpetofauna, mammals and fishes provide excellent foraging for the Saltwater Crocodiles.

[22] http://www.ohpcltd.com/Rengali/silent

[23] Panda M, Murthy TVR, Samal RN, Lele N, Patnaik AK and Chand PK (2017). Diversity Of True and Mangrove Associates Of Bhitarkanika National Park (Odisha), India. Int. J. Adv. Res. 5(1), 1784-1798

The mangrove species have changed at the river and creek because of increased salinity. Further investigations on the condition and trends in each mangrove species should be conducted, especially *Heritiera littoralis* and *Heritiera kanikensis* (Kanika Sundari), which are two rare varieties.

As the mangrove plants expand, they tend to replace the existing meadows, which are an important habitat for grazing wild animals and some birds. The Forest Department is working to maintain and extend the meadow habitat.
Bhitarkanika is a low-lying area with tidal water submerging the landmass during high tides. It is often water-logged after heavy rainfall or flooding. Development of high mounds and increasing the height of eroded mounds are needed to maintain this essential habitat for many animals.

PRESSURES AND TRENDS

- The mangrove area is increasing, through the efforts of the Forest and Wildlife Department. The community's uses of the mangroves for housing material, firewood and Nalia Grass for developing utility items such as baskets were reduced after the declaration of Bhitarkanika National Park.
- The community is cooperating with the Forest Department, and mangrove cutting for domestic purposes has reduced dramatically.
- During the super cyclone of 1999 and after many subsequent less intense cyclones, the local community has realised the importance of mangroves as a buffer and protective barrier.
- None of the mangrove species has been eliminated from the site although species such as *Heritiera littoralis* and *Heritiera kaniakansis* (Kanika Sundari) are now rare.
- The growth and spread of Hental *(Phoenix paludosa)*, or Mangrove Date Palm, is static. The cutting of this mangrove is restricted even though it tends to grow more prolifically when more branches are cut.

Table 4 *Trend analysis of mangroves in Bhitarkanika*

Mangroves	Trend	Description
Mangrove area	Low to high	The mangrove area is increasing each year as the Forest Department is undertaking planting to fill gaps and establish new areas of forest.
Mangrove species	No change	There is no change in the mangrove species, but the species mix varies due to changes in salinity.
NTFP Collection	High to low	Before the declaration of the national park in 1998, the local community was free to collect fuelwood as well as timber for constructing their houses, but now this use is restricted.

2.2.3 Saltwater Crocodile

The Saltwater Crocodile *(Crocodylus porosus)* is a keystone species of the Bhitarkanika Ramsar site. Bhitarkanika has the largest habitat of this endangered species in India. Brackish wetlands and natural lush green mangroves are the peaceful abodes of crocodiles in Bhitarkanika. The population of the crocodiles has increased around 17%, from 1498 in 2008 to 1798 in 2020[24]. Although the average survival rate of the hatchlings is low, at 1% to 1.5%, the life span of the Saltwater Crocodile ranges from 70 to 100 years.

The crocodiles are opportunistic feeders, preying on crabs, fish, birds, turtles, pigs, small cattle, buffalos and wild animals. The usual mating period is from January to March. A female crocodile starts the process of nesting from the first week of May. She takes approximately 15 days to set up a safe shelter for her offspring. She digs a small hole of 5 inches in a swampy area in a high place, out of reach of the high tide, creates a layer of Hental leaves *(Phoenix paludosa)* inside the hole and lays her eggs. A female crocodile lays 50 – 60 eggs at a time. The eggs are again covered with two or three layers of Hental or Nalia

[24] As per crocodile estimation data of the Forest and Environment Department, Rajnagar Division, Kendrapada

Grass and then with wet mud, which after drying creates solid protection for the eggs. The hatchlings emerge after 60 to 72 days during July. The mother tends to stay near the nest throughout the incubation. She also creates a 'body pit' of 1 – 2 feet depth and keeps her newborn babies in the pit for a couple of months. Then gradually she carries them into the creek. Most of the hatchlings become prey during their struggle to grow as yearlings.

During their egg-laying season, female crocodiles become aggressive and can attack humans at even the slightest sign of intrusion into their nesting area. Thus, the Forest and Environment Department close the sanctuary from May to July for the protection of the crocodiles as well as tourists. The Forest Department is making a special efforts to conserve the Saltwater Crocodile.

2.2.4 Olive Ridley Turtles

Gahirmatha Beach is the largest nesting ground of the Olive Ridley Sea Turtle *(Lepidochelys olivacea)* in the world. The Olive Ridley Sea Turtle is an endangered species. Every year, 3.5 to 4.5 lakh Olive Ridley Turtles visit Gahirmatha for egg-laying. Beach erosion is occurring at the Bhitarkanika Ramsar site because of the sea-level rise and the coastal dynamics, which are reducing the sandy area and restricting the Olive Ridley Turtles from mass nesting.

The Olive Ridley Turtles are sensitive to changes in temperature, requiring temperatures of at least 30°C to 35°C for hatching. If the temperature goes beyond 35°C, the turtles may not come to the Bhitarkanika Ramsar site (Gahirmatha). The mortality of Olive Ridley Turtles is increasing because of non-climatic threats such as marine fishing using gill nets by trawlers. In the last decade (2010 – 2020), the cumulative mortality in the area was a very significant 9019 individuals (data of Rajnagar Forest Division). Illegal marine fishing by trawlers (including distant water boats) often continues despite a ban on offshore fishing during November – March.

2.2.5 Ecosystem services

Tourism has been increasing every successive year with the exception of 2020 and 2021, when there were fewer tourists due to the Covid pandemic. The livelihoods related to tourism are increasing, such as hospitality services (restaurants, canteens, lodging, homestays, boating, shops and local guides). Livelihood activities in the site need to be tightly managed although this has proved not to be easy.

The role of the Eco-development Committees (EDC) is to protect the forest and wild animals and cooperate with the Forest Department in implementing the annual forest management plan. The Forest Department has provided some assets to EDC to create a revolving fund for their operation. Except for some villages benefiting from eco-tourism, in many of the periphery villages, the EDCs are non-functional, as the community is not directly receiving any livelihood benefit from the mangrove forest. There is a lack of a keen interest in the conservation of the national park. In any case, there are restrictions on the collection of forest produce.

Agriculture, fishing (fresh, brackish and marine) and aquaculture (prawns) are the main livelihood activities, and all have an impact on local ecosystems. The fish species diversity has been reduced as fish production has increased. There is a need to study the reasons for the fish species diversity change.

2.2.5.1 Agriculture

Key trends in the local agricultural sector are: (table 5)

- Earlier, farmers were having a yield of 34.6 quintals of paddy per hectare without using fertilisers, but now the yield is 30 quintals per hectare with fertilisers.
- Some local varieties of paddy such as Belandi, Raspanjar, Panikoili and Bhundi are no longer cultivated as the yield from these varieties is low.
- The sowing period was predictable a decade ago; now there is delayed sowing.
- The coconut and banana production and area have reduced.

Table 5 Trend analysis for agriculture in Bhitarkanika

Item	Trend	Description
Paddy	High to low	Paddy yield has reduced by 22% due to the increasing salinity of agriculture land as prawn farming in the area has increased.
Cattle population	High to low	Cow and bull numbers have reduced dramatically due to mechanised agriculture.
Small ruminant population	High to low	Common grazing land is reducing due to encroachment, overgrazing and poor management.
Availability of grazing land	High to low	Due to the reduction of common lands and conversion of agricultural lands to aquaculture.

2.2.5.2 Fishing

Key trends in the fisheries sector: (table 6)

- A decade ago, fishermen used to catch fish within 5 km of the Brahmani and Baitarani estuaries, but now they have to travel to 50 to 150 km to have a good catch.
- The annual marine fish catch has increased by 96%, from 4797.64 MT in 2009 – 2010 to 9399.38 MT in 2019 – 2020, in eight fish landing centres all around the sanctuary (Barunei, Gopalpur, Talachua, Tantiapal, Kandarapatia, Jamboo, Kharanashi and Kajalapatia). This is as reported by the Kendrapada District Marine Fishery Department.
- Fishermen used to catch Hilsa with an average weight of 2 – 3 kg. During the past decade, the size of Hilsa has reduced to 250 – 500 g.
- Telia of weighing 20 kg were available during winters earlier. Now due to the reduced duration of the season, these fish are less available.
- 15 years ago, fishermen used to catch white Chandi fish in tons, but now in one catch, they are netting about 10 – 20 kg. Earlier the size of Chandi fish was 1000 – 1200 g, which was fetching Rs. 4000 per kg. Now the size of the fish has been reduced to 500 – 700 g, which is selling for Rs.1200 per kg.
- Fish species such as Hunda, Kantia, Adikantia, Telia, Tudi, Dhuma, Hilsa and Sankucha have almost vanished from the catches.

Table 6 Trend analysis of fish in Bhitarkanika

Item	Trend	Description
Total fish production (Inland)	Low to high	Promotion of Gift Tilapia scheme by the state government along with the Rahu, Bhakuda and Mirkali.
Riparian fish production	No change	There is no change in the availability of fish (micro-prawn) in the river.
Availability of riparian fish – species diversity	High to low	The fish species such as Hilsa and Chandi are decreasing due to siltation in the river mouth and over-harvesting of juvenile fish. The change in the duration of the winter has greatly reduced the quantity and size of the Telia.
Marine fish Production	High to low	The fishermen have to go far away into the sea (>50 km) for fishing; earlier, they could catch 5–10 km away.
Brackish water prawn (Tiger Prawn)	High to low	Due to the low price at the time of harvesting, the high price of feed and medicines and being prone to highly infectious diseases.
Benami prawn cultivation	Low to high	Less prone to highly infectious diseases
Freshwater prawn	High to low	Due to the availability of freshwater for a shorter period (hydrology and climate change related factors). They are prone to highly infectious diseases.

2.2.5.3 Aquaculture

Trends in aquaculture are significant for their continuing impacts on local ecosystems:

- Brackish water, as well as freshwater prawn farming is increasing. The Fisheries Department is also promoting pond-based farming of prawns and fish production.
- Ten years back, farmers were farming Tiger Prawns (which weighed 100 – 200 g), but gradually farmers have changed the variety and adopted Benami (White Prawn, 50 – 60 g). This is because Tiger Prawns are vulnerable to virus attacks. The duration of harvesting of Tiger Prawn culture was 150 days, which was too long and made the Tiger Prawn culture vulnerable.
- Earlier, the prawn cultivation was close to the river and creek banks for easy access to water, but due to regulations by the government, farmers are prohibited to do aquafarming within 500 m of river or creek banks.

Table 7 *Trend analysis of aquaculture ponds in Bhitarkanika*

Item	Trend	Description
Number of ponds	Low to high	The community is now converting their agricultural land to ponds for prawn cultivation.

2.2.5.4 EDCs, tourists and local livelihoods

The community is not taking an interest in the joint forest management process as they are not benefiting from the activities. A few EDCs are operational, but annually, about 75,000 tourists visit Bhitarkanika. Thus, the Forest Department is in the process of re-activating EDCs.

Table 8 *Trend analysis of social-economic aspects in Bhitarkanika*

Item	Trend	Description
Number of people migrating out of the area	Low to high	Due to the population growth of and poor scope for employment, the migration out of the area is high.
Number of Tourists	Low to high	The number of tourists is increasing, and accordingly, the service providers such as boats and hotels are increasing. In the past decade, the number of tourist boats increased from 20 to 80.
Motorboats	Low to high	
Drinking water availability	High to low	The potable groundwater table is decreasing day by day. Earlier 183 – 198 m; now 213 – 229 m.

2.3 Current threats

Current threats to the Bhitarkanika Ramsar site and associated trends include:

- Sea erosion is increasing. Six villages of Satbhaya gram panchayat have been submerged by rising seas.
- Damage from cyclones increasing: The unique geo-climatic condition of the Bhitarkanika Ramsar site makes it prone to cyclones. Strong cyclones have been hitting Bhitarkanika frequently, which is damaging mangroves and other sea front ecosystems such as beaches. Major cyclones that affected the Bhitarkanika Ramsar site are the super cyclones that occurred in October 1999, Phailin, in October 2013, Fani cyclone, in May 2019, Bulbul, in November 2019, and Amphan, in May 2020.
- The salinity of the rivers is increasing due to sedimentation at the river mouth and reduced water inflows as per the perception of communities. The operation of Rengali Dam in the upper catchment area of the Brahmani river controls the inflow of freshwater.

- Increase in encroachment of forest land and fringe areas for prawn cultivation, i.e. observed in prohibited areas within 500 m of natural water bodies, sanctuaries and national parks.
- Illegal inland aquaculture increasing: Over the years, due to the restriction of fishing in the Bhitarkanika National Park and reduced yield in agriculture, the community is more inclined to adopt brackish water prawn culture. In the surrounding area of the national park, a large chunk of agricultural land adjacent to rivers and creeks has been converted into prawn farms. Untreated effluents from the farms are discharged into the nearby rivers and creeks, which is affecting the aquatic fauna and mangroves. According to a study conducted by the Centre for Land Resources Management, School of Natural Resource Management, Central University of Jharkhand, Ranchi in 2018, aquaculture increased from 20.76 km^2 in 2002 to 44.86 km^2 in 2017 as seen in satellite imagery.
- Illegal marine and river fishing increasing: Despite a ban period imposed by the Forest and Marine department for the conservation of aquatic species, illegal river and marine fishing is continuing in parts of restricted areas. Fishermen are not abiding by the regulation imposed by the government. As prescribed by the government, the fishing trawlers are supposed to use turtle escape device (TED)-fitted nets for marine fishing, but they are using gill nets for fishing, which is causing mortality of Olive Ridley Turtles, as well as obstructing the growth of juvenile fish.
- Serious pollution of rivers and creeks: The river Brahmani receives effluents discharged by the National Aluminium Company (NALCO), Fertilizer Corporation of India (FCI) and Talcher Thermal Power Plant Station (TTPS). These industries utilise coal and are an active source of fluorides, nitrogen compounds, cyanide, chromium, fly ash and other suspended solids.

Table 9 *Current threats to the Bhitarkanika Mangroves Ramsar site*

Threats	
Natural threats	
Cyclones	• Super cyclones in October 1999, Phailin in October 2013, Hudhud in Oct 2013, Fani in May 2019, Bulbul in November 2019 and Amphan in May 2020
Erosion	• Due to currents and wave direction, the northern side of the river will erode, and it will deposit on the southern side of the riverbank • 6 villages of Satabhaya overtaken by the sea • Agriculture lands are collapsing into the river due to Brahmani river erosion (Subarnapur village)
Siltation	• Sea level rise, prawn ponds, soil erosion due to frequent floods, and deforestation in the upper catchment area
Salinity	• Hard infrastructure protection measures (Rengali dam and its operation) are restricting environmental flows into the Brahmani river, and so the salinity of the river water fluctuates unnaturally
Irrigation scheduling	• Irregular releases of water from reservoirs are affecting the normal cycle of freshwaters flows
Temperature	• Average temperatures of Bhitarakanika area increasing
Floods	• Kendrapada district has been affected by floods in 1999, 2001, 2003, 2006, 2007, 2008, 2009, 2011 and 2013.
Threats from people	
Brackish water aquaculture/ fish farming	• River water pollution through discharge of untreated effluents from the prawn farm • Farm ponds are increasing in numbers and extent every year
Poaching	• Poaching has reduced the populations of deer and the wild boar significantly
Wood cutting	• Wood cutting is controlled by the Forest Department, but wood cutting for firewood continues as the cost of natural gas is increasing.

Threats	
Threats from people	
Over-fishing	• Violation of rules controlling the use of gill nets specific nets prescribed by the government by local and distant water trawlers
Fishing bans during nesting not effective	• Poor community members dependent only on fishing and some distant water trawlers defy the ban
Increased population in the area	• Growing population demands for water and resources
Tourism and solid waste	• Use of plastic and poor management of plastics by eco-tourism operators and tourists

2.4 Stakeholder roles and perceptions

Stakeholders and groups involved in the use or management of the Ramsar site, and its natural resources are listed in Table 10 including official organisations, the private sector, user groups and communities.

Table 10 *Stakeholder analysis in Bhitarkanika*

Stakeholder	Rights, roles and responsibilities at the Ramsar wetland site
State Wetland Authority	• Development of Integrated Management Plan for the state Ramsar sites in coordination with Central/State Forest and Environment Departments • Mobilisation of funds for the implementation of plans in coordination with various departments of the state/national government such as the Forest and Environment, Water Resource, Marine, and Fishery and Wildlife departments • Undertaking/facilitating scientific research related to the flora and fauna of the Ramsar site • Capacity building of various stakeholders in the management and protection of wetlands
District Forest Office, Wildlife Division Mangrove Forest Division, Rajanagar	• Conservation of mangrove forest • Mangrove plantation in the evicted encroached landmass • Plantation work was undertaken in the gap areas and evicted area • Clearing of siltation from the riverbed • Controlling the fishing in the restricted area • Issue of boat licence for eco-tourism • Restriction of farm ponds for prawn culture within 500 m of the riverbank • Conducting a census of the wildlife
Forest Range Office, Dangamal Range	• Maintaining meadow land for the grazing animals • Creating new and renovating existing water bodies • Eviction of sites where there is illegal brackish water prawn culture in and around Bhitarkanika National Park and the sanctuary • Protecting the mangrove forest • Plantation of mangrove plants as required for gap filling and covering encroachment-evicted lands • Monitoring and patrolling for safety and security around the protected area • Monitoring the siltation deposit in the creeks and clearing it for proper inflow of brackish water/freshwater • Engaging Eco-development Committee members around the national park area for better protection and conservation • Cleaning of siltation from creeks for free movement of patrolling boats • Hatching the eggs of crocodiles in a controlled environment

Stakeholder	Rights, roles and responsibilities at the Ramsar wetland site
Fishery Department, Kendrapara District District Fishery Office	• Promotion of inland fish production • Promotion of Tilapia Fish production • Promotion of freshwater prawn culture • Construction of fish jetties for fish landing • Using remote sensing and GIS for monitoring the fishery sector • Regular stock enhancement in reservoirs with basic infrastructure such as hatcheries, nurseries, fingerling rising centre • Implementation of various livelihood schemes related to fish production and marketing • Capacity building of fish farmers • Coordination with Forest and Revenue departments for approval of licences for inland aquaculture
Marine Fishing Department, Rajanagar	• Marine Fishery Department issues licences to fishermen/fish entrepreneurs for fishing in the sea • Enforcement of ban period for marine fishing (November – May) for protection of breeding of Olive RidleyTurtles • Regulating fishing during the breeding period of Olive Ridley Turtles. Fishermen were given compensation for the ban period of Rs.7500 (INR) or $103 (USD). Out of 10,000 registered fishermen, 2200 were covered under the scheme as per the fund allocation • Supporting various safety and social welfare programmes for the fishing community
Marine Police	• During monitoring of boat licenses, if they find any illegal fishing case during the ban period, they hand over the case to the Forest Department. • Marine Police provide support to the Forest Department on request for evacuation of people having illegal fish/prawn ponds.
Eco-development Committee, Bankual	• Protect the forest animals by informing the forest guards in case they enter into the residential areas • Protection of mangroves by discouraging cutting • Undertaking plantation with the support of the Forest Department • Cooperating with the Forest Department by abiding with the laws/restrictions of the Forest Departments • Engaged in local tourism and support services of the Forest Department – tourist boat operation, canteen operation and cleanliness
APUA (NGO)	• Improve agriculture production, replacing community dependence on forest resources
Department of Water Resource, Aul, Kendrapada	• Manages nearly 710.625 km of the embankment of four major rivers, namely, the Brahmani, Baitarani, Gobari and Luna. The main responsibility of this department is the protection of river embankments from erosion due to tidal hits and natural calamities such as floods.
Department of Rural Water and Sanitation, Kendrapada	• Responsible for ground and surface water management to supply potable and safe drinking water and sanitation facilities to local communities. The RWSS is planning for piped water supply using surface water flow from the river Brahmani. It is apprehensive that there will be a further decrease in the inflow of freshwater to the sanctuary areas.
Eco-development Communities (EDCs)	• EDC meetings are not regular • EDC members are not clear about their roles/activities • Communities are not aware of the Site Management Plan details • Communities have no clarity on the rules and regulations of the Forest and Marine departments • A few EDC members are working in the canteen of the national park, involved in housekeeping, cleaning, etc. • EDC members are involved in plantation activities

Stakeholders' perceptions and concerns relating to the existing climate regimes and recent extreme events in Bhitarkanika are shown in Table 11.

Table 11 *Stakeholders' perceptions and concerns for Bhitarkanika Mangroves Ramsar site*

Stakeholder	Perceptions and concerns relating to recent extreme events and climate trends
District Forest Office, Wildlife Division	• Sea erosion is increasing. 6 villages of Satabhaya Gram Panchayat were submerged by the sea • Change of density of some species of mangrove due to salinity increase.
Forest Ranger, National Park	• Siltation in the wetland areas and creeks/rivers is observed due to cyclones every year. • An increase in siltation obstructs the inflow of freshwater, which is leading to an increase in salinity, which affects the mangrove species and aquatic flora and fauna species in the long run • The salinity gradient is affected by climate change. Based on the salinity gradient, mangrove species density varies from place to place • There is a need for further research to be conducted on the impact of climate change on salinity • Species such as *Heritiera littoralis* and *Heriteria kaniakansis* (Kanika Sundari) are reducing
State Wetland Authority, Chilika Development Authority	• Sea erosion, river erosion and siltation of river mouth are the most significant changes for the Ramsar site • Increasing natural disasters like cyclones, floods are causing damage to boats, trees and houses at and around the site, according to Wildlife Conservation in Odisha
Fisherman of Subarnapur Village	• In the last 5 years, river embankment erosion has been very fast. In the last 20 years, the width of the river has increased 3 times • Many acres of agricultural land are already merged with the river • 20 years before, the village was about 1 km away from the village, but now the river is only 200 m away from dwellings • The opposite side of the Brahmani river is regenerating mangrove forests naturally
Fisherman of Bhanja Prashad Village	• Fishermen used to catch Telia fish – about 20 – 25 kg per day during winter – these fishes are now less common • They have been experiencing reduce a reduced winter season and an increase in average temperature during winter • Fishermen used to catch Hilsa fish with an average weight of 2 – 3 kg before 10 years; presently the catch of Hilsa is reduced to 250 – 500 g • Hental mangrove species' extent is decreasing
Fisherman of Talachua Village	• Telia, Hilsa and Chandi fish quantity and size have reduced significantly • The diversity of the fish catches has also reduced
Farmers of Junus Nagar Village	• New diseases are attacking prawns, maybe due to temperature changes • Cyclones are occurring twice a year, but mangroves are protecting local villages
Farmers of Rangani Village	• Due to erratic rainfall, sometimes the seed sowing period is changing. Earlier farmers used to raise paddy seedlings by the last week in May, now they are raising during mid-June • Temperature is increasing, irregular rainfall, summer duration is increasing, and winter duration is decreasing • Coconut and banana quantity and size have been reduced.

2.5 Institutional arrangements and management plans

2.5.1 Forest Department

The Divisional Forest Officer, Mangrove Forest Division (Wildlife), Rajnagar is the Wildlife Warden of Bhitarkanika Sanctuary and National Park. He is also the administrative head of the division. He is responsible for the implementation of the legal provisions of different acts and rules pertaining to forests and wildlife. The Divisional Forest Officer is assisted by an Assistant Conservator of Forests who looks after the protection and management of the protected area. He also assists the Divisional Forest Officer in preparing reports and returns. The Bhitarkanika protected area has been divided into two ranges, namely, Kanika Wildlife Range and Rajnagar Wildlife Range. The Range Officer is primarily responsible for the protection of the habitat. He patrols regularly within his jurisdiction along with the staff working under him. He also discharges duties under the Code of Criminal Procedure and prepares prosecution reports to be sanctioned by the Divisional Forest Officer. He acts as a sub-disburser to the Divisional Forest Officer and is responsible for the proper utilisation of government money.

Each range has been divided into sections. Both Kanika and Rajnagar ranges have been divided into three sections each.

- Kanika Range: (I) Dangmal, (II) Talchua and (III) Khola
- Rajnagar Range: (I) Rajnagar, (II) Gupti and (III) Satbhaya

The Forester is responsible for the protection of the area under his jurisdiction. He also acts as a sub-disburser to the Range Officer. There are 11 beats under Rajnagar Wildlife Range and 12 beats under Kanika Wildlife Range. Each beat is manned by a Forest Guard. The Forest Guard is responsible for regular patrolling in his area. He is also responsible for making and reporting important observations.

2.5.2 Bhitarkanika Management Plan

The Management Plan (2008-09 to 2017-18) was prepared by the Mangrove Forest Division (Wildlife), Rajnagar, Kendrapara, Orissa[25]. The plan runs for 10 years and is an improvement over the earlier plan prepared by this division for the period from 2001-02 to 2010-11. The Divisional Forest Officer and his team prepared the Management Plan guided and supported by the Principal Chief Conservator of Forests (Wildlife) & Chief Wildlife Warden, Orissa, Bhubaneswar and the Regional Chief Conservator of Forests.

The Management Plan aims to rehabilitate and maintain the site and reduce threats including:

- Habitat protection (mangroves and wildlife)
- Restoration of mangrove forests
- Protection of forests from fire
- Boundary fencing
- Maintenance of forest roads (inland and water roads)
- Restoration of creeks
- Digging and restoration of freshwater ponds
- Development of meadows
- Removal of unwanted species of weed (*Eupatorium* spp., *Acanthus* spp. species)
- Publicity, education and awareness
- Construction of watchtowers
- Anti-poaching squad
- Hiring patrol boat/vehicle
- Maintenance of VHF equipment
- Forest settlement: establishment of the legal status of forest
- Legal action against offenders
- Reward to informers of offences

[25] In 2021, the Odisha Wildlife Department notified the updated sanctuary management plan for the time period 2019-20 to 2029-30.

- Creation of mounds
- Census of animals
- Training of frontline workers in:
  - management of protected areas,
  - advanced technology and application,
  - GPS surveys,
  - use of tranquillizing equipment,
  - nursery raising techniques,
  - maintenance of VHF equipment,
  - use of closed-circuit cameras
- Eco-Development Committees:
  - Strengthening of EDCs
  - Economic development activities for adjacent villages

2.5.3 Wetland Research and Training Centre

The Wetland Research and Training Centre (WRTC) was established in 2002 with support from the 10th Finance Commission. In 2010, the WRTC was expanded and upgraded through support from the World Bank under the Odisha component of the Integrated Coastal Zone Management Project. The centre is in close proximity to Chilika Lake and offers a unique opportunity to perform in situ research related to wetland ecology, conservation, and biodiversity. As a nodal centre for Chilika Development Authority for conducting wetland related research, the centre has the following mission:

- continuously monitor the lake health and take precautionary measures through a systemic research approach
- implement a systemic ecological approach to characterize, document, and preserve the biodiversity of the lake
- apply tools of molecular biotechnology to understand the genetic diversity of different biodiversity components
- develop a strong research programme for cutting-edge science in the area of wetland ecology and conservation
- promote collaborative research at the national and international levels for expert opinion in specialised disciplines
- disseminate the knowledge regarding wetlands and their functions to coastal communities, school children and policymakers

2.5.4 Fisheries and Animal Resources Development Department, Government of Orissa/Directorate of Fisheries

The Government of Odisha has come up with the Odisha Fisheries Policy, 2015 (vide Gazette notification No. 1282, Dt. 2nd September 2015). The policy is intended to be a pioneer in aquaculture development and fisheries extension for ensuring food security, livelihoods, the welfare of fishers and employment generation.

The policy aims to address sustainable utilisation, protection/promotion of nutritional security, livelihood security of the fishing community, gaps in the legal and regulatory framework and their enforcement, gaps in the administrative structure and processes, financing mechanisms including subsidies, technology and extension support as well as social and environmental implications.

The directorate is responsible for the development of the fisheries sector in Odisha, with the following objectives:

- Implementation of Odisha Fisheries Policy, 2015 to double the fish production of the state and to raise exports to Rs.20,000 crores
- Maximum utilisation of water bodies with stocking of quality seed
- Generating employment and higher incomes in the fisheries sector
- Improving socio-economic conditions of traditional fisherfolk and fish farmers and doubling the income of fishers
- To acquire self-sufficiency in the inland sector
- Conservation of aquatic resources and genetic diversity

3 CLIMATE CHANGE AT BHITARKANIKA MANGROVES

3.1 Current and past climate

The Bhitarkanika Mangroves Ramsar site is located in Kendrapada district, of Odisha state. It is a coastal plains region that has tropical climate conditions. In general, there are three main seasons in this region. Summer begins in February and extends up to the end of May. The monsoon usually starts in June and extends up to October. The period from November to January is the winter. The area is prone to severe cyclonic storms almost every year from April to May and from October to November. Also, there are occasional tidal bores – strong tidal surges that push up the river against the current.

3.1.1 Precipitation

The average rainfall during the monsoon in the district of Kendrapada is about 1115.1 mm (Figure 5). This accounts for app roximately 77% of the average annual rainfall, which is 1529.1 mm. However, the rainfall is distributed over nine months during the year, from February to November. The main rainy months are July and August, with a mean of 311.4 mm and 343.0 mm, respectively (IMD, 2020)[26]. During the last three decades (1989 - 2018), the rainfall in Kendrapada showed a slightly increasing trend for the monsoon and a gradually decreasing trend annually.

The average frequency of rainy days during the monsoon season ranges from 45.7 to 47.8 days. At the annual scale, the average frequency is about 59.5 to 66.3 days (Figure 6). IMD's historical observations show that the frequency of rainy days has significantly increased throughout 1989 - 2018, causing a higher flood risk within this area.

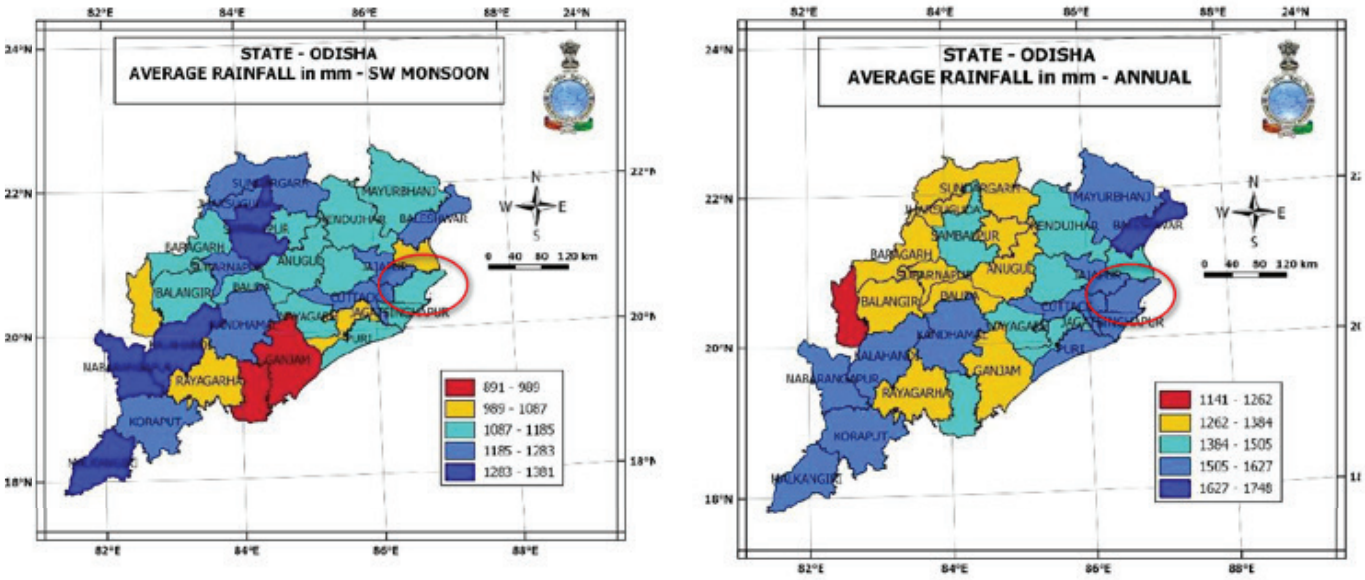

Figure 5 *Mean rainfall pattern over districts of Odisha. Kendrapada district is indicated by the red circle. (Source: IMD 2020)*

[26] Observed Rainfall Variability and Changes Over Odisha State. Issue No. ESSO/IMD/HS/Rainfall Variability/20(2020)/44. Issue Date: January 2020

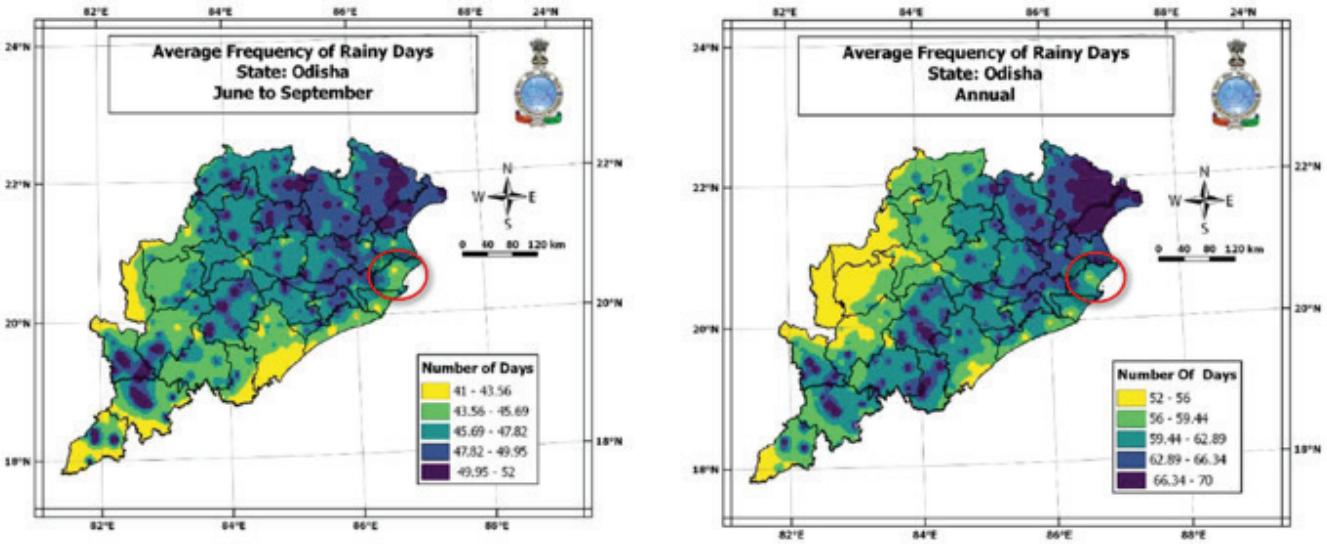

Figure 6: *Average frequency of rainy days for monsoon and annually in Odisha. Kendrapada district is indicated by the red circle (Source: IMD 2020)*

3.1.2 Temperature and humidity

The maximum temperature goes as high as 39°C in April and May, and the lowest temperature is about 14°C in December and January. May is usually the hottest month, while December is the coldest month of the year. The humidity in this area is high throughout the year because of its proximity to the sea and varies between 75% and 95%. Detailed data on humidity are not available.

3.1.3 Historical extremes

Droughts and floods are recurrent phenomena in Odisha and at Bhitarkanika. The years in which droughts and flood events were experienced are indicated in Table 12. The area is prone to severe cyclonic storms from April to June and from October to November. During cyclones, at times the wind speed may reach up to 200 km per hour though this is rare. Cyclonic winds with speeds up to 60 - 70 km per hour are common and occur several times each year.

Table 12 *Historical flood and drought events recorded at Bhitarkanika*

Year	Event	Year	Event
1955	Flood	1976	Severe drought
1956	Flood	1977	Flood
1961	Flood	1978	Hailstorm, whirlwind
1965	Severe drought	1979	Severe drought
1966	Drought	1980	Flood
1967	Cyclone, flood	1981	Tornado, whirlwind, flood and drought
1968	Cyclone, flood	1982	Severe flood, drought, cyclone
1969	Flood	1984	Drought
1970	Flood	1985	Flood
1971	Severe cyclone, flood	1986	Drought and cyclone
1972	Flood and drought	1987	Drought and cyclone
1973	Flood	1988	Drought
1974	Severe drought, flood	1989	Drought
1975	Flood	1990	Flood

(Source: Mangrove Forest Division, 2019)[27]

[27] Mangrove Forest Division, 2019. Management Plan for Bhitarkanika Wildlife Sanctuary and National Park.

3.2 Bioclimate zones adjacent to Bhitarkanika mangroves

The mapping of bioclimate zones around Bhitarkanika (Figure 7) shows that the lowland coastal areas are Extremely Hot and Xeric (very dry), while some of the upper catchment areas are classified as Extremely Hot and Moist. The eastern coastal edges of the Ramsar site are also classified as Extremely Hot and Moist. It is probable that with climate changes in temperature and rainfall, the bioclimate classification for the Bhitarkanika mangroves will not change significantly. With the small increases in precipitation in the monsoon period and increased temperatures, it is likely that the eastern coastal edges will remain Extremely Hot and Xeric.

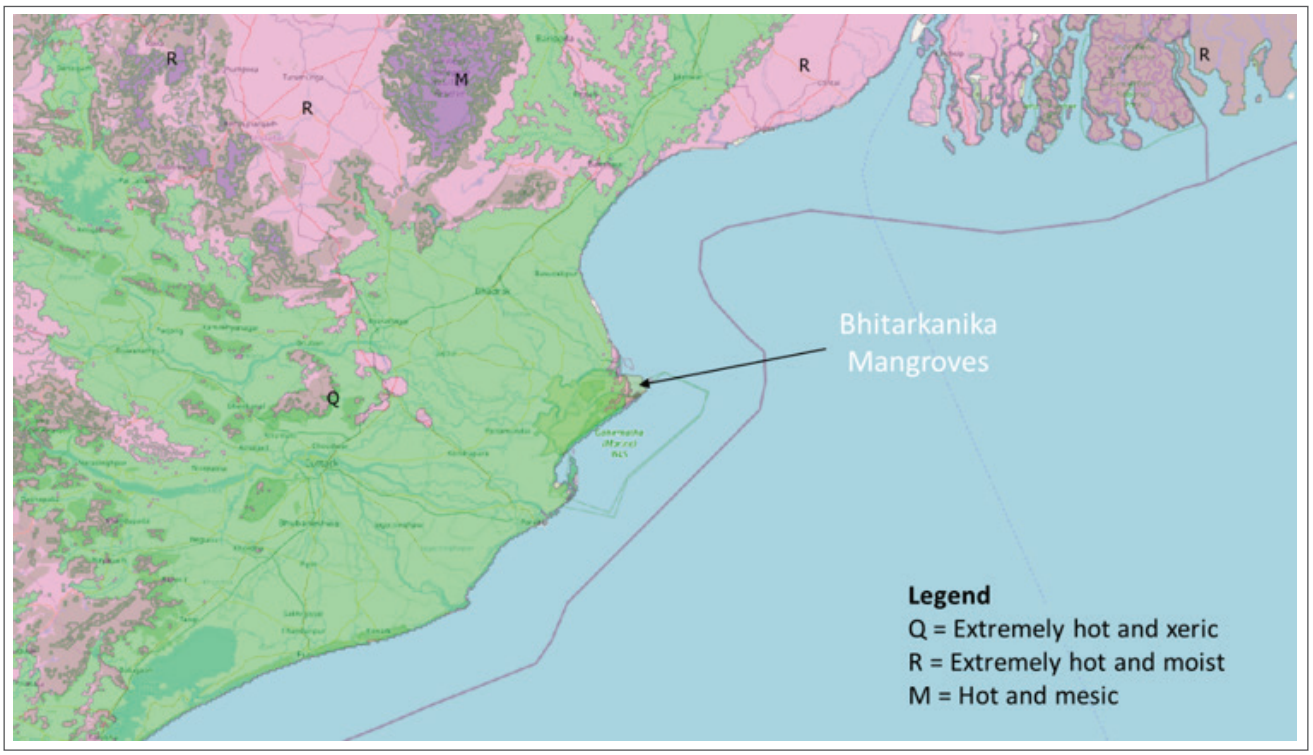

Figure 7 *Bioclimate zones around Bhitarkanika Ramsar site*
(Source: Adapted from Global Environmental Stratification (GEnS_v3))

3.3 Climate change projections

This section presents projections for the precipitation and temperature at the Bhitarkanika Mangroves Ramsar site by the 2050s, with respect to a baseline period of 1960 – 1990. These results were generated using an ensemble mean 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.

3.3.1 Projections of precipitation

Projections of the total precipitation change by the 2050s, with respect to the baseline period of 1960 – 1990, at Bhitarkanika Mangroves are shown in Table 13. The total rainfall is projected to increase by 3.9% or 48.3 mm, from 1262.2 mm to 1310.4 mm, during the monsoon season (June – October). The projection map (Figure 9) shows that the increase in rainfall during the monsoon will be more significant for immediate upstream areas (by 11.2 % or 140 mm) of the catchment.

By the 2050s, precipitation in summer (February – May) is projected to decrease by 13.7 mm or 8.2%, from 167.0 mm to 153.7 mm. A slight decrease of 3.7 mm (5.5%) is also projected for winter (November – January). Decreases in rainfall will be more significant in mangrove forested areas compared with upstream areas of the catchment (Figures 8 and 10).

The effects on the Ramsar site of reduced rainfall combined with increasing extraction of ground and surface waters in the catchment should be studied. The drought conditions in the 2050s will be more severe compared to the baseline period. Poor rainfall can directly affect mangrove productivity, growth and survival by increasing salinity levels in the mangrove forested areas.

Table 13 *Projections of seasonal precipitation change by the 2050s at Bhitarkanika Mangroves Ramsar site*

Season	Baseline 1960 – 1990 (mm)	Projection 2050s (mm)	Change (mm)	Change (%)
Summer (February - May)	167.0	153.7	-13.3	-8.2
Monsoon (June - October)	1262.2	1310.4	48.3	3.8
Winter (November - January)	67.0	63.3	-3.7	-5.5

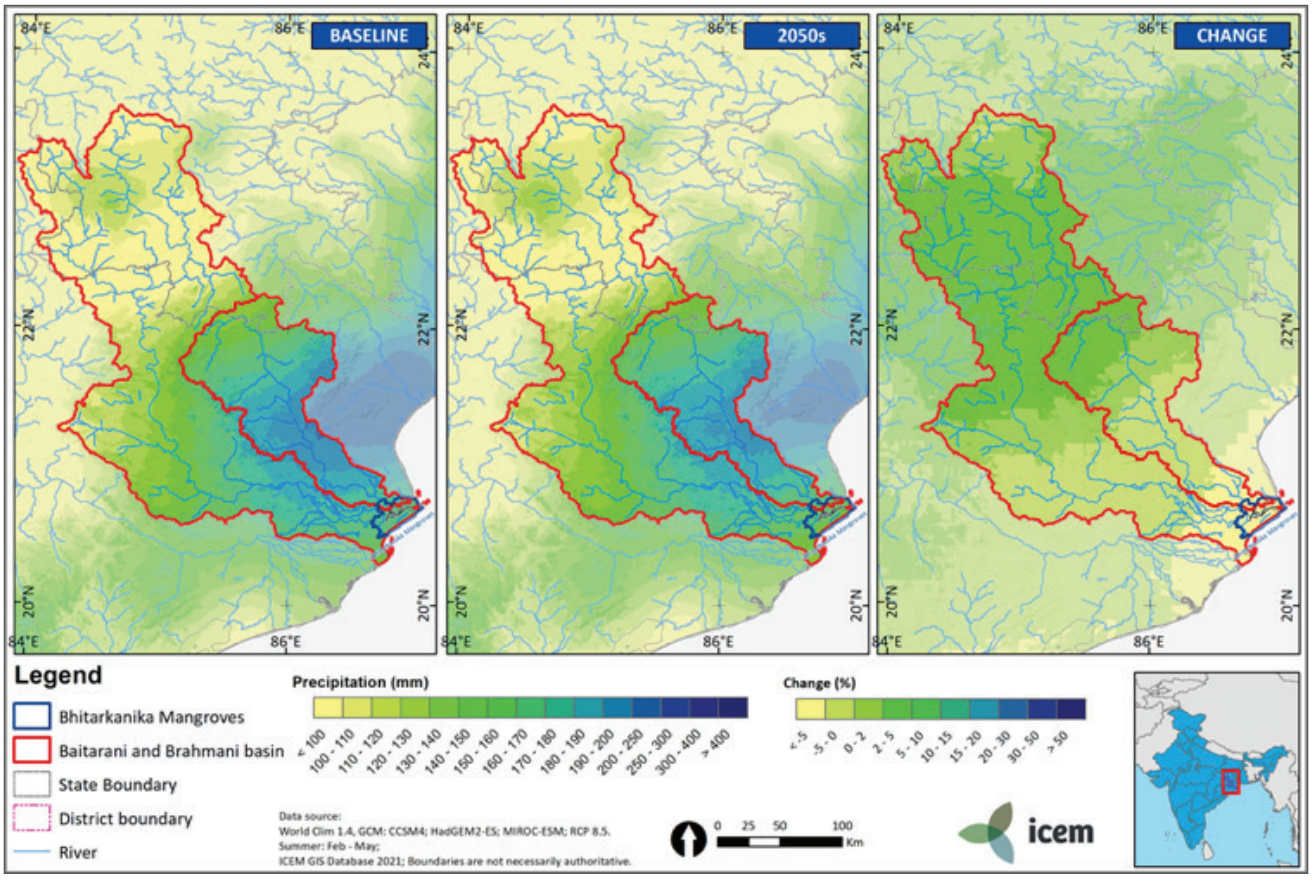

Figure 8 *Projections of precipitation change during summer (February – May) in Baitarani and Brahmani basins*

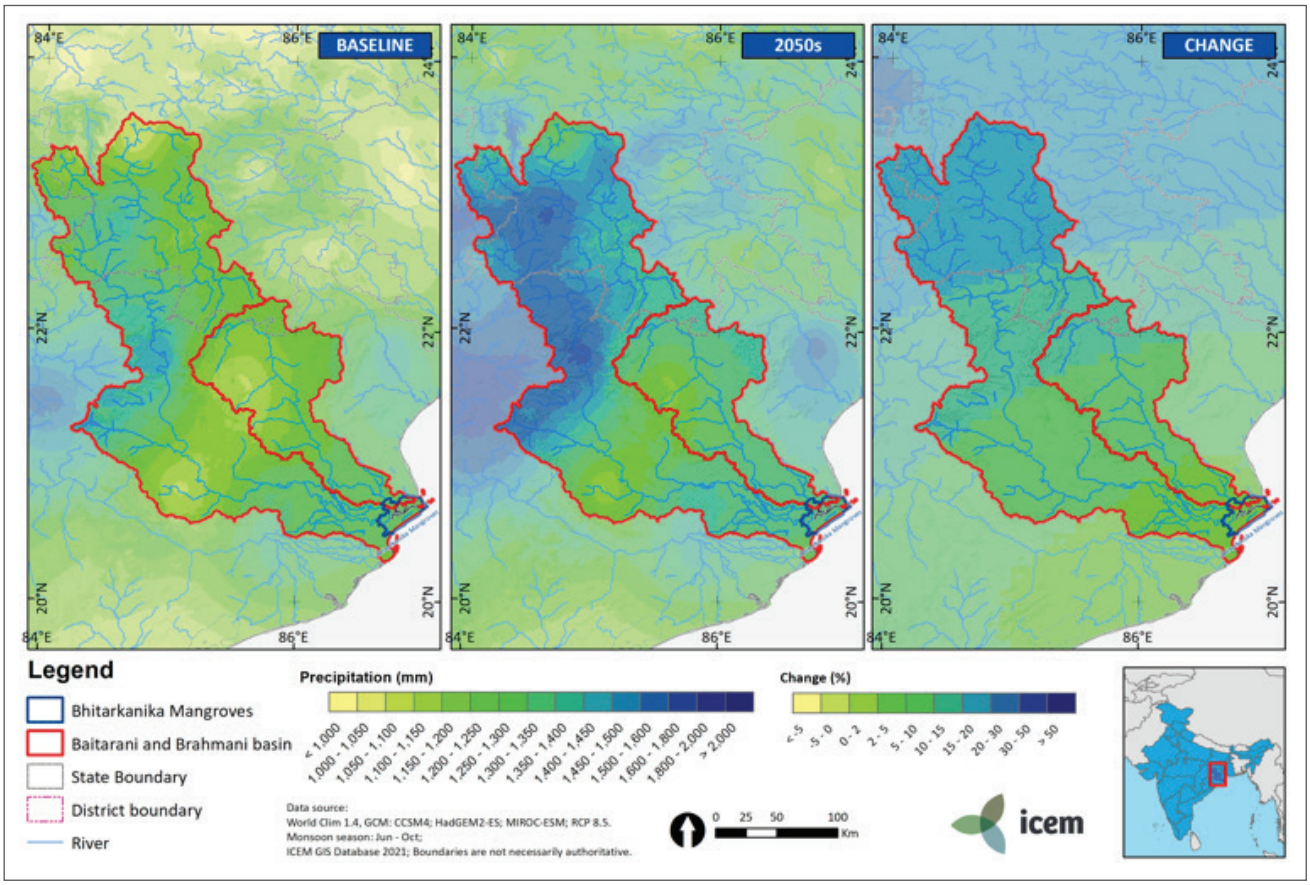

Figure 9 *Projections of precipitation change during monsoon (June – October) in Baitarani and Brahmani basins*

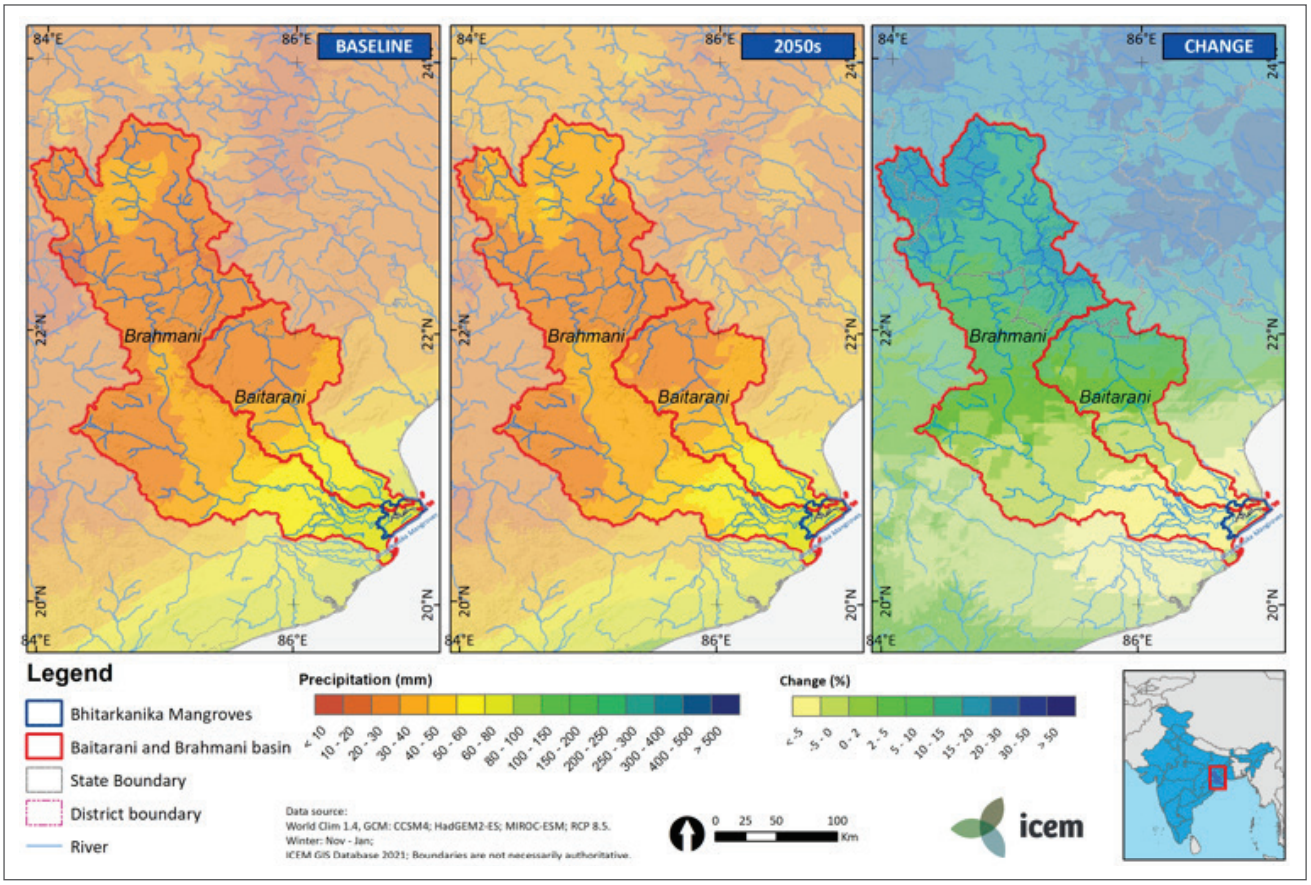

Figure 10 *Projections of precipitation change during winter (November – January) in Baitarani and Brahmani basins*

3.3.2 Projections of temperature

Projections of average temperature and its changes by the 2050s, with respect to the baseline period of 1960 – 1990, at the Bhitarkanika Mangroves Ramsar site are shown in Table 14. The temperature is projected to increase by 1.9°C to 2.1°C by the 2050s.

Summers in the 2050s will be warmer, with the average maximum temperature projected to increase by 2.1°C (from 33.5°C to 35.6°C). Summer will be an extreme season with limited rainfall and higher temperatures, which will place stress on the forests and associated species.

The average maximum temperature during the monsoon season is projected to increase from 31.6°C to 33.5°C (+1.9°C). Winters are projected to be warmer, with an increase in the average maximum temperature of 2.0°C by the 2050s (from 27.6°C to 29.6°C).

The increase of average maximum temperature is projected to be more significant for immediate upstream areas of the catchment (Figures 11-13). The increase in temperature as projected in the Bhitarkanika Mangroves can disrupt physiological processes, including a reduction in photosynthetic rates, which will reduce leaf formation, which will affect the net productivity. A high surface temperature also increases evapotranspiration, thus rendering water more saline.

Table 14 *Projections of seasonal temperature change by 2050s at Bhitarkanika Mangroves Ramsar site*

Season	Baseline 1960 – 1990 (°C)	Projection 2050s (°C)	Change (°C)
Summer (February - May)	31.6	33.5	1.9
Monsoon (June - October)	33.5	35.6	2.1
Winter (November - January)	27.6	29.6	2.0

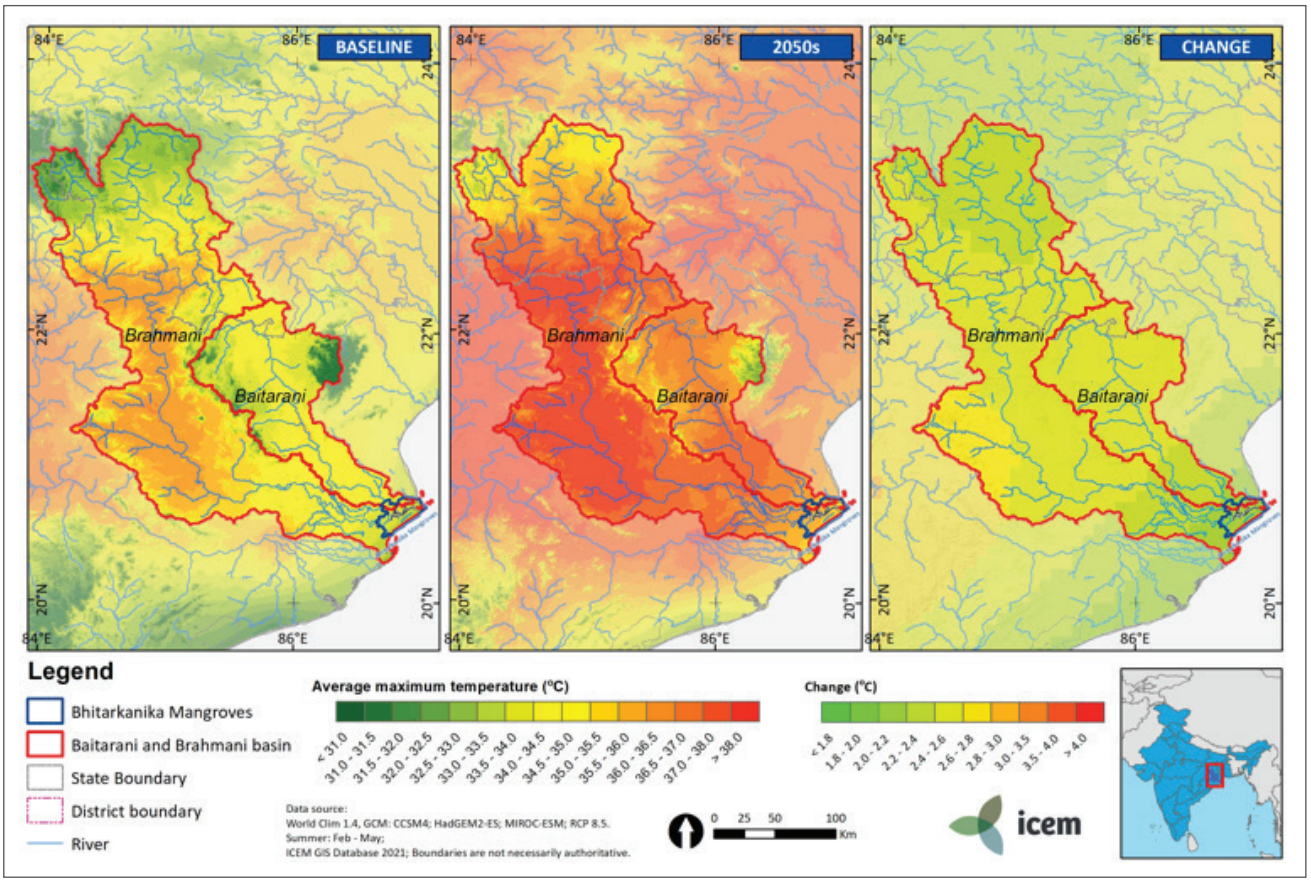

Figure 11 *Projections of change in average maximum temperature during summer (February – May) in Baitarani and Brahmani basins*

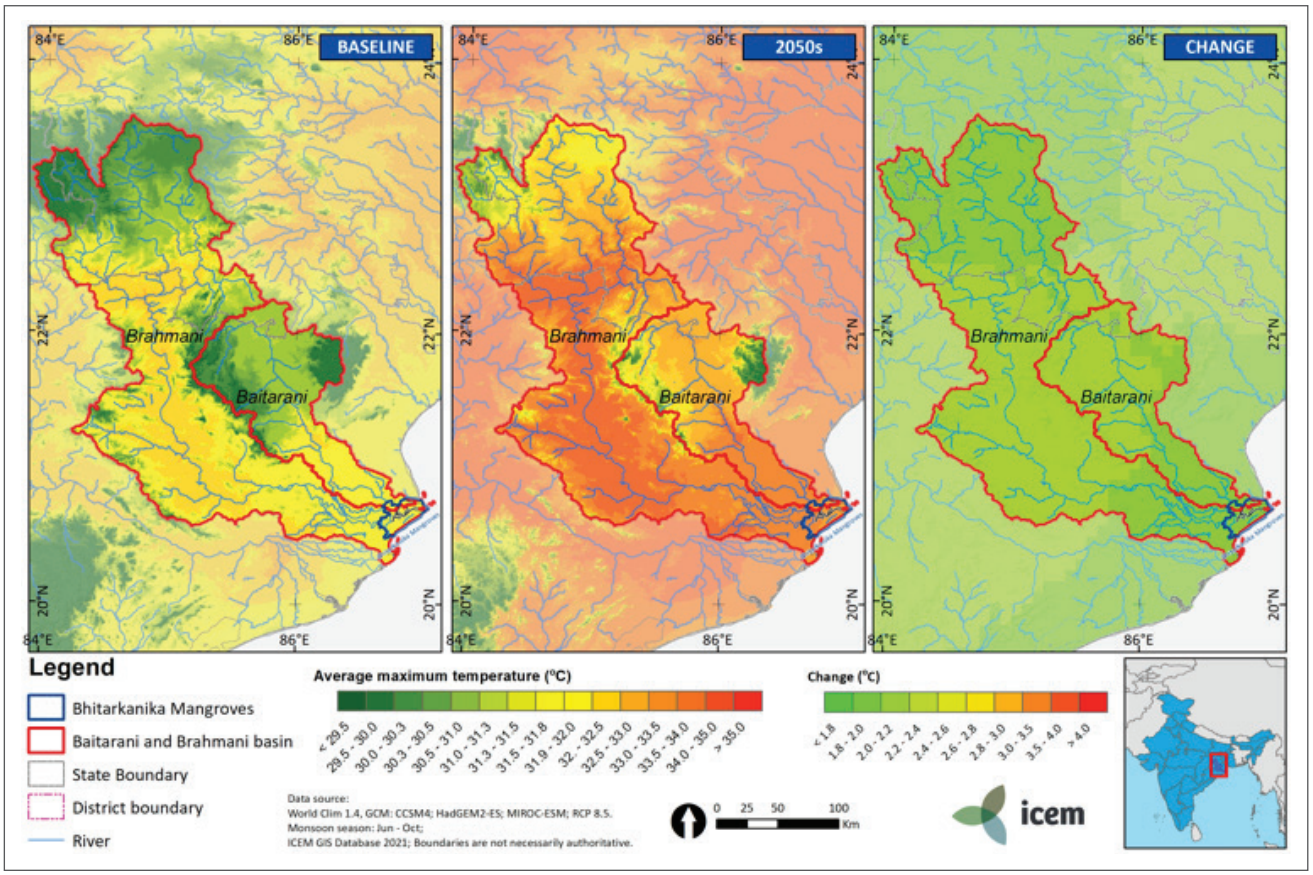

Figure 12 *Projections of change in average maximum temperature during the monsoon (June – October) in Baitarani and Brahmani basins*

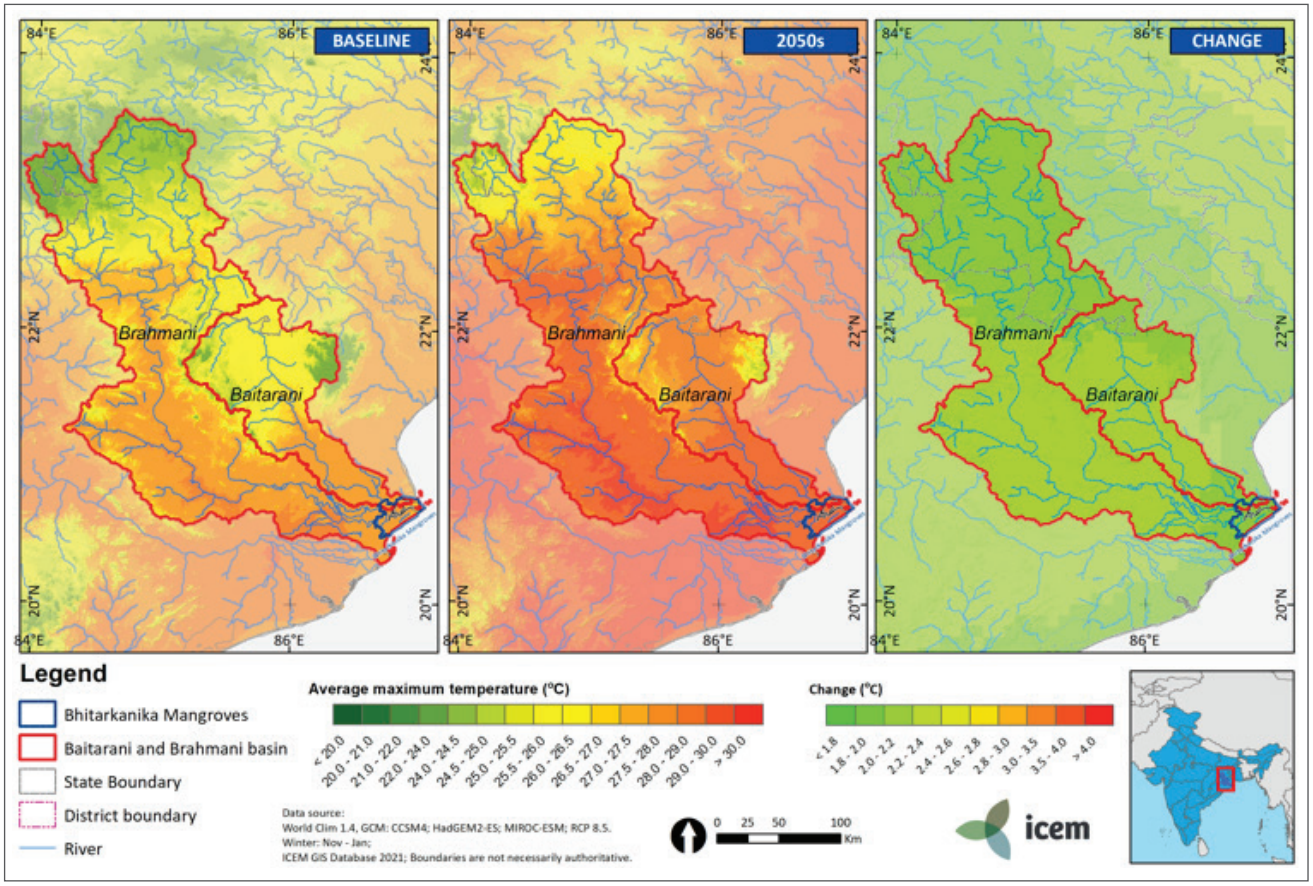

Figure 13 *Projections of change in average maximum temperature during winter (November – January) in Baitarani and Brahmani basins*

3.3.3 Extreme events and sea-level rise

Bhitarkanika is likely to suffer from a hotter period during June – October, with increased average temperatures, and this period will be followed by a period of decreased rainfall during November – February that may cause drought hazards. With climate change, extreme cyclones and storm surges are expected to increase in frequency and intensity in the coastal areas of Odisha. Bhitarkanika has a very 'high' risk of an increased frequency of cyclones and a 'moderate' to 'high' risk of storm surges up to 5 m (Figure 14) (Ahammed and Pandey, 2020))[28]. Climate change is also expected to bring heavy, intense and unexpected precipitation that will cause flooding of low-lying areas.

The sea-level rise is an important consequence of climate change, both for societies and for ecosystems. 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, such as a month or a year i.e., long enough for fluctuations caused by waves and tides to be largely removed. The sea-level rise is projected at 0.5 m by the 2040s for the Ramsar site coastline (Figure 15)[29].

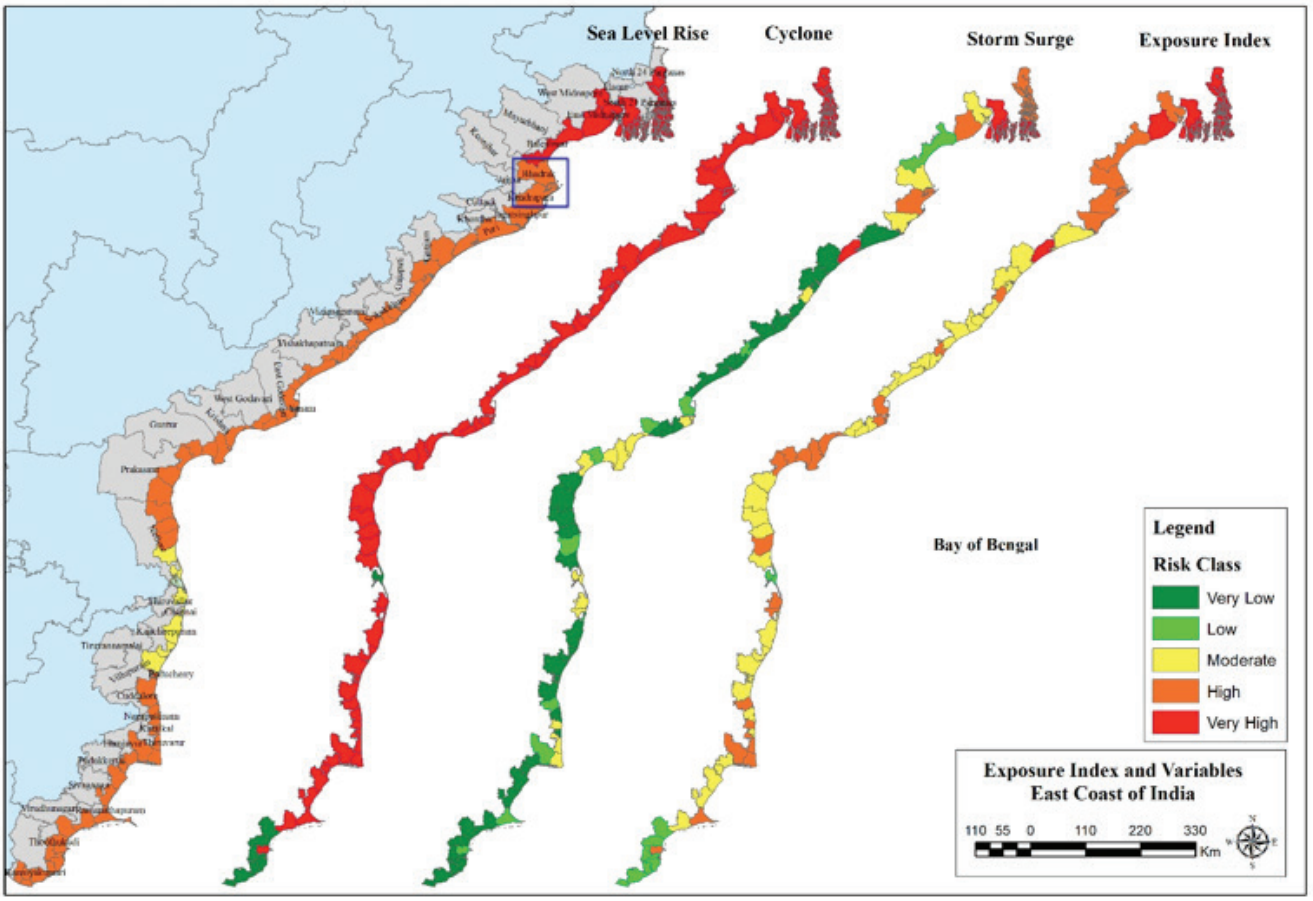

Figure 14 *Risks of cyclones, storm surges and sea-level rise due to climate change along the eastern coast of India. The Bhitarkanika coastline is highlighted in the blue box. (Source: Ahammed and Pandey, 2020)*

[28] 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.

[29] CWC, 2015. Operational Research to Support Mainstreaming Integrated Flood Management in India under Climate Change Vol. 5b Modelling Report Brahmani-Baitarani.

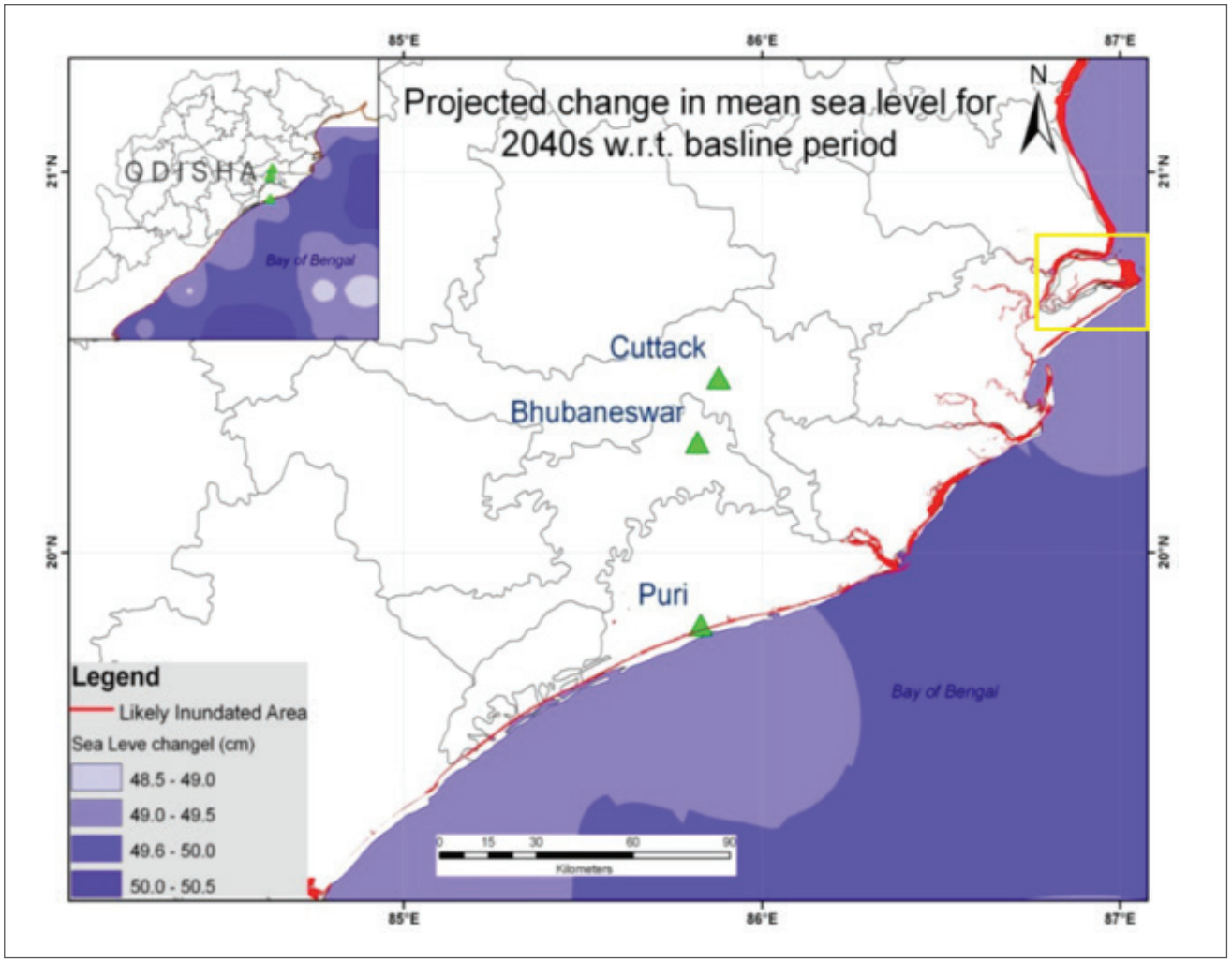

Figure 15 *Projected change in mean sea level by the 2040s along the Bhitarkanika coastline. The Ramsar site is in the yellow box. (Source: CWC, 2015)*

4 IMPACT AND VULNERABILITY ASSESSMENT

4.1 Vulnerability assessment summary

The vulnerability assessment scores for the key assets of Bhitarkanika mangroves are shown in Figure 16. The vulnerability of the assets is described in more detail below. The target assets are the mangrove habitat, Saltwater Crocodile, Bhitarkanika catchment, fisheries, Olive Ridley sea turtles and tourism. The Vulnerability Assessment Matrix for each of these target assets is attached as complementary material to this report (a list of files is provided in Annex 2). The direct and indirect impacts of the various climate change parameters are explained.

In summary, the climate change threats including a precipitation increase during the rainy season and a decrease during the dry period. An overall increase in temperature and extreme events including the sea-level rise, cyclones, and storm surges makes the target assets of the Bhitarkanika Ramsar site highly vulnerable. Mangroves are the habitat of crocodiles, in addition to supporting fisheries and tourism. Mangroves are vulnerable to climate change and extreme events; therefore, their vulnerability will also impact the dependent assets including crocodiles and fisheries as well as many other assets such as migratory birds and other wildlife. The mangrove vulnerability is ‘very high’ for the decrease of rainfall during the dry season (February – May) and ‘high’ for the increase in temperature during the monsoon and summer periods. Mangroves are highly vulnerable to sea-level rise and increases in the frequency of cyclones.

The Saltwater Crocodile is a relatively resilient species, but temperature changes will affect its survival, and the sea-level rise and storm surges will reduce the area of the suitable habitat. On the other hand, the Olive Ridley sea turtles are highly vulnerable to extreme events, like sea-level rise and cyclones. The storm surges would make their beach nesting habitat highly vulnerable.

In terms of impact on ecosystem services, overall, the fisheries are highly vulnerable to all the extreme events and the decrease in rainfall during the dry season and increase in temperature during winter (November – January). In the case of tourism, the number of visitors will fall significantly due to increased extreme events such as cyclones and storm surges and loss of the visiting habitat to the sea-level rise.

The catchment area is very large and extends several hundreds of kilometres inland from the sea. The vulnerability of the catchment area is 'high' to the decrease in rainfall during the dry season and increase in temperature during summer and winter. The catchment is also vulnerable to an increase in the frequency of cyclones, which cause excess rainfall and flooding.

The adaptive capacity of the biological assets – mangroves, crocodiles, fisheries and sea turtles – is mostly 'low' and 'very low' to all the extreme events. However, the adaptive capacity of crocodiles to cyclones is 'high'. The decrease in rainfall during the dry season lowers the adaptive capacity of fisheries. The adaptive capacity of the tourism sector is 'low', due to the sea-level rise and frequent cyclones and potential losses in facilities. The adaptive capacity of the catchment is 'low'. The increase in temperature in winter (November – January) will increase the demand for water and environmental flows. Also, the catchment adaptive capacity during frequent cyclones and the related flooding is 'low'.

Threats	Mangrove habitat					Saltwater Crocodile					Catchment					Fisheries					Gahirmatha – Olive Ridley Sea Turtles					Tourism				
	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul	Exp	Sen	Imp	Adc	Vul
Precipitation																														
Increase of rainfall during Monsoon (Jun–Oct)	H	M	H	H	M	H	L	M	VH	M	H	M	H	H	M	L	L	L	VH	L	VL	VL	VL	VH	VL	M	M	M	VH	L
Decrease of rainfall during dry season (Feb-May)	VH	H	VH	M	VH	M	M	M	M	M	H	H	H	M	H	H	H	H	L	H	L	M	M	L	M	VL	VL	VL	VH	VL
Temperature																														
Increase of temperature during the Monsoon (Jun–Oct)	H	M	H	M	H	M	H	H	H	M	M	H	M	M	M	L	M	M	M	M						VL	VL	VL	VH	VL
Increase in temperature during summer/pre-monsoon (Feb-May)	H	H	H	M	H	VH	H	VH	M	VH	H	H	H	M	H	M	H	M	M	M	M	H	H	M	H	M	M	M	H	M
Increase of temperature during the winter (Nov–Jan)	M	M	M	M	M	VL	VL	VL	H	VL	M	M	M	L	H	H	H	H	M	H	L	H	M	M	M	VL	VL	VL	VH	VL
Extreme events																														
Sea level rise	VH	VH	VH	L	VH	VH	H	VH	L	VH						M	M	M	L	H	VH	VH	VH	VL	VH	VH	H	VH	L	VH
Cyclones	VH	VH	VH	L	VH	VH	L	H	H	M	H	H	H	L	H	H	M	H	L	H	VH	VH	VH	VL	VH	VH	H	VH	L	VH
Storm surge	H	H	H	L	H	H	VH	VH	VL	VH						M	M	M	L	H	H	H	H	L	H	H	H	H	M	VH

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 16 *Summary Vulnerability scores of Bhitarkanika Mangroves*

4.2 Mangrove habitat

In Bhitarkanika National Park, there are 29 true mangrove species and 72 mangrove associates. Since 2014, the Odisha State Forest Department has been planting, and so the mangrove cover is increasing. The health of the mangrove forest is important because the forests are a lifeline for the ecosystem, which is home to a rich diversity of plants and animals and acts as an environmental cushion for the coastline.

The baseline shows a trend of increasing salinity at all the stations. According to the Mangrove Forest Division (MFD) of Bhitarkanika, denudation and saline blank formation are increasing in the Bhitarkanika forest blocks, which amounted to 1700 acres in 2015. The denudation has occurred among the *Avicennia* and *Excoecaria* species, popularly known as Bani and Guan.

Climatic factors such as temperature and precipitation are strongly associated with mangrove biophysical parameters and health in Bhitarkanika Sanctuary. A study of the extent and health of the Bhitarkanika mangroves by 2050, which used different biophysical parameters as indicators of mangrove health, found that the Gross Primary Production (GPP), Leaf Area Index (LAI) and leaf chlorophyll (CHL) will experience a net decrease of 7.7%, 20.83% and 25.96%, respectively, compared with the mean annual value in 2016. The study also concluded that despite conservation efforts, the current extent of dense mangroves will decrease up to 10%. By 2050, patches of mangrove along the south-west and northern coasts of Bhitarkanika Sanctuary are projected to decrease in GPP and are at a higher risk of disturbance (Kumar et al., 2017).

4.2.1 Impact of climate change on the mangrove ecosystem

The mangroves are the key habitat defining the Bhitarkanika Ramsar site. The projected seasonal changes in precipitation and temperature, coupled with extreme events, will exert different pressures on the mangrove ecology – some will be positive and some negative. The resulting trends will reflect the balance between positive and negative effects and overall impacts upon the mangrove cover and survival. Four types of impacts identified through the vulnerability assessment process that can be expected:

- **Changes in the mangrove area** - tree cover and density. The decreasing trend of dense mangroves is expected to be exacerbated by the loss of suitable areas for mangrove growth due to the sea-level rise and increased damage to existing stands of mangroves from cyclones and storm surge. Increased salinity within the creeks especially due to decreased rainfall in the dry season causing saline bank formations would lead to reduced natural revegetation in the damaged areas. The trend due to climate change is likely to be increased through the loss of mangrove cover and density.
- **Changes in growth of mangroves** - There is likely to be a balance between the increased growth of the mangroves, which will be enhanced by the increased rainfall during the wet season, and the decreasing growth caused by lower rainfall and increased salinity in the dry season. The wet season is the main period of growth, and the mangroves tend to be more dormant during the dry season, i.e., they have an in-built adaptive capacity to the harsher conditions of the dry season, and it is possible that the changes in rainfall during wet and dry seasons would tend to balance the growth of the mangroves. However, when this is combined with increasing temperatures at the hottest times of the year, during the pre-monsoon and monsoon periods, it is likely that mangrove health and growth will be impaired overall. The trend with climate change is likely to be decreased mangrove health and growth.
- **Changes in reproductive health - flowering, seed formation and survival of seedlings and saplings.** Mangrove flowering and seed setting, as well as propagule formation occur during the pre-monsoon and early monsoon when it is both hottest and driest. Increasing temperatures during this time and the increased salinity in the creeks may affect reproductive health, tending to decrease seed and propagule production. Increased salinity and pollution in the creeks, coupled with sea-level rise, may reduce the survival of seedlings and saplings. With the sea-level rise taking seeds and propagules into unsuitable areas for mangrove re-vegetation and storm surges wiping out recently vegetated areas the reproductive capacity of the mangroves is likely to be decreased with climate change.
- **Changes in species distribution** - Bhitarkanika is renowned for the diversity of mangrove species, but it is likely that climate change will lead to changes in that diversity, with the less saline-tolerant species tending to die back and not reproduce or re-vegetate blank areas. The sea-level rise and pollution in the creeks will add to the pressure on the more sensitive species. The mangrove species diversity in Bhitarkanika is expected to decrease with climate change, as the more resilient species, such as *Avicennia* spp, become even more dominant.
- **Increased carbon emissions from degraded mangrove ecosystems** - If climate change induces loss and degradation of the mangrove habitats, there is a risk that the sequestered carbon in the trees, soil and mud will be released, further contributing to greenhouse gas emissions.

4.2.2 Impact of precipitation change

It is projected that there will be a 3.9% increase in rainfall during the monsoon (June – October) by the 2050s (i.e., 48.2 mm, from 1262.2 mm to 1310.4 mm). There will be a more significant increase for immediate upstream areas in the catchment (11.2% or 140 mm). Increases in precipitation result in a decrease in salinity and an increase in the productivity and growth of mangroves. It is also associated with higher runoff, erosion and silt deposition, resulting in an accretion of land and associated mangrove migration to newly built land. Erosion and waterlogging during flood periods will increase, leaving very few highlands for wildlife such as deer, wild boars and reptiles. The additional extreme rainfall events may lead to a die-off of sensitive species (e.g., shrimps, crabs, frogs, fishes and crustaceans) due to toxic flushes of pollutants from sediments in catchment creeks. The vulnerability to mangroves is medium due to increased precipitation during the monsoon.

An 8.2% decrease in rainfall during the dry season (February – May) is projected by 2050 (13.3 mm, from 167.0 mm to 153.7 mm). More significant decreases will occur in mangrove forested areas compared with upstream areas in the catchment. Mangroves will be increasingly stressed during the dry season by increased salinity in creeks. Growth and health during this season will be reduced. Denudation on saline banks has been recorded in the Bhitarkanika Forest Block – a trend likely to continue with decreased dry season rainfall. The indirect impacts are drying up of wetlands and reduced water holding capacity of the wetlands, which leads to drought. Loss of productivity of mangrove habitat leads to reduced food availability for fish and crocodiles at the top of the food chain. Forest cover and species mix are likely to shift, leading to the loss of species with lower salt tolerance. Degradation of mangrove forests can release carbon stored in biomass and wetland soils. In summary, mangrove forest vulnerability to decreased precipitation during the dry season is ‘very high’.

4.2.3 Impact of temperature change

An overall increase in temperature during all three seasons is projected. During the monsoon (June – October), the average maximum temperature will increase by 1.9°C from 31.6°C to 33.5°C. During summer/pre-monsoon (February – May), the average maximum temperature will increase by 2.1°C, from 33.5°C to 35.6°C, and during winter (November – January) it will increase by 2.0°C, from 27.6°C to 29.6°C.

The temperature has a negative relationship with all three biophysical parameters (GPP, LAI, and CHL). The increase in temperature in the Brahmani and Baitarani basins can disrupt physiological processes, including reduced photosynthetic rates, which are linked to a decrease in leaf formation, which will affect the net productivity of the mangroves. High surface temperatures also increase evapotranspiration, thus rendering water more saline. The excessive salinity creates a saline aquifer over a period of time as the existing vegetation dies. The increase in temperature creates shifts in species composition that in turn, can affect the overall metabolism and productivity of mangroves in wetlands. This would impact indirectly the migratory birds and turtles. The vulnerability to increased temperature of mangroves is ‘high’ during the monsoon and summer periods and ‘medium’ during the winter period.

4.2.4 Impact of extreme events

The sea-level rise is projected to be 0.5 m by 2040 for the Ramsar site coastline. Mangroves along the northern coastal section of the site and the central coastal strip will be lost amounting to approximately 20% of the forests. Also, fringing mangroves along creeks will be lost. The species composition of the mangrove forest species will change with the loss of saline intolerant species. Indirect impacts: the mudflat area will be reduced, the crocodile habitat will be reduced, and Olive Ridley Turtle nesting areas will be reduced due to loss of beach areas. The vulnerability of the mangroves to the sea-level rise is ‘very high’.

A ‘very high’ risk of increased frequency of cyclones will cause damage to the mangroves. Since systems that are under frequent stress tend to recover slowly, the vulnerability of the mangroves to the increased frequency of cyclones can be classified as ‘very high’. Further, there is a ‘moderate’ to ‘high’ risk of increasing severity to storm surges of up to 5 m. This will lead to loss of fringing mangroves along creeks. The vulnerability of mangroves to storm surges is ‘very high’.

4.3 Catchment

The Bhitarkanika Ramsar Site is in the deltaic region of the Brahmani river (799 km length) and the Baitarani River (355 km length) systems. The catchment area (between longitudes 83°55′E and 87°3′ E and latitudes 20°28′ and 23°38′′N) is a zone of influence on the health of the site. The Brahmani river is one of the major inter-state east-flowing rivers of peninsular India. The basin falls in Jharkhand, Chhattisgarh and Odisha and drains an area of 39,033 km^2 [30]. A major portion of the Baitarani basin lies in Odisha; except for a small portion in Jharkhand, draining an area of 10,982 km^2. The combined Brahmani and Baitarani basins extend over 51,822 km^2 [31]. The Bhitarkanika Ramsar Site area is about 650 km^2 i.e., 1.25% of the total catchment area. There are over 42 existing dams, nine projects under construction and several planned in the catchment area of these two rivers[32].

The catchment is a critical part of the Bhitarkanika mangrove site because it is the source of all the freshwater and terrestrial sediments flowing into the site, which in turn affect the salinity of the creeks. The salinity is one of the main growth factors of mangroves. Agricultural runoff and industrial wastewater discharges in the catchment contribute to the major polluting loads in the creeks. **The salinity has been increasing due to human activities such as:**

- The operation of the Rengali and other dams causing less freshwater to flow into the Brahmani river system
- Siltation of river mouths due to reduced inflows
- Increases in water consumption for irrigation, aquaculture, tourists and domestic requirements of people in local villages
- Pollution from aquaculture ponds

Those activities lead to significant changes in the density and distribution of plants and key species – mangroves, crocodiles, turtles, and birds. The water drawn from the wetland for aquaculture ponds and the polluted drainage water from the ponds entering the wetland creeks and rivers is a particular concern given their proximity to the Bhitarkanika ecosystems.

3.3.1 Impact of Climate change on the catchment area

The key climate change impacts on the catchment affecting the Bhitarkanika Ramsar site are:

- **Changes in the freshwater reaching the Ramsar site and hence in the salinity of the creeks:** The increased rainfall in the catchment during the monsoon period is likely to be beneficial for the mangrove ecosystem at this time of year. The salinity in the creeks will be reduced somewhat, providing improved conditions for mangrove growth. However, the increased demand for water within the catchment may limit the benefits to the mangroves especially if as expected, additional water storage is built. Any reductions in the normal flow reaching the site will be exacerbated by the projected decrease in rainfall and higher temperatures during the dry season. That will tend to increase evapotranspiration and the demand for irrigation water and the domestic water supply. The trend due to climate change is expected to continue reducing the freshwater input to the site and increasing salinity in the creeks.
- **Changes in sediment from soil erosion in the catchment:** The increased rainfall during the monsoon period is likely to increase the sediment transport from the catchment into the Ramsar site, especially if the intensity of the rainfall events increases as projected. The terrestrial sediment will be deposited in the creeks likely to reduce tidal interchange and building up the elevated area possibly above the tidal levels making it unsuitable for mangrove colonisation. The available area for colonisation will also be influenced by the sea-level rise. The geomorphological trends in the Ramsar site due to climate change impacts in the catchment are expected to lead to reduced areas suitable for mangrove colonisation within the confines of the Ramsar site, though suitable areas outside the Ramsar site may be created.
- **Changes in the pollution load in the catchment affecting water quality:** Unless measures are taken to control the pollution, the water quality in the Ramsar site is likely to deteriorate further under climate change. Increased catchment rainfall in the monsoon, will bring down more contaminated run-off and industrial effluents and sediments into the site, whilst the decreased rainfall in the dry season and higher temperatures, especially in the pre-monsoon period, will tend

[30] http://www.cwc.gov.in/mero/about-basin

[31] https://indiawris.gov.in/wiki/doku.php?id=brahmani_and_baitarni

[32] https://indiawris.gov.in/wiki/doku.php?id=dams_in_brahmani_and_baitarni_basin

to concentrate pollutants reaching the site. The discharge of water from aquaculture ponds into the creeks will exacerbate the pollution load coming from the catchment. This will impact the growth and survival of mangroves, crustaceans and fish living in the mangrove ecosystems.

- **Climate change will undoubtedly have an impact on land use practices and cover as well as on the demand for freshwater in the catchment and operation of dams:** These aspects have not been specifically assessed because they would require a much wider review of the existing land use and dam operation and potential changes.

4.3.2 Impact of precipitation change

The rainfall is projected to increase by 3.9% during the monsoon (June - October) (i.e., 48.2 mm, from 1262.2 mm to 1,310.4 mm). A more significant increase of 11.2% for immediate upstream areas in the catchment is projected (i.e., 140 mm). This increase will be concentrated in more intense events. Erosion of the riverbanks and siltation will increase. Indirectly, aquifers will be recharged in the catchment area. The vulnerability to increased precipitation will be ‘medium’.

A decrease in rainfall of 8.2% during the dry season (February - May) (i.e., -13.3mm, from 167.0 mm to 153.7 mm), will decrease inflows and increase the pollution of the surface water and groundwater. The sources of contamination are domestic sewage, garbage, soil erosion, mining areas runoff and other activities with extensive recreational use of the streams and the river. Indirectly, the intense agriculture will draw more water for irrigation, especially during drought periods, reducing the water available in the catchment area for ecosystem services. The vulnerability of the catchment to decreased precipitation will be ‘high’.

4.3.3 Impact of temperature change

An overall increase in temperature during all three seasons is projected. During the monsoon (June - October) , the average maximum temperature will increase by 1.9°C, from 31.6°C to 33.5°C. The increase in temperature during the monsoon period will deepen low pressure zones and cause more rainfall in the catchment. Indirectly, high surface temperature also increases evapotranspiration and increases the demand for irrigation water and overall water demand in the catchment, especially during the pre-monsoon period. Water pollution will be high during summer. The vulnerability of the catchment area will be medium during monsoon and high during summer and winter periods.

4.3.4 Impact of extreme events

The sea-level rise along the Ramsar site coastline is projected to be 0.5 m by 2040. Yet, in the catchment, a very small area is exposed to the sea-level rise, and so it will have a ‘low’ vulnerability to the sea-level rise. Storm surges of up to 5 m pose ‘moderate’ to ‘high’ risk which would have the least impact on the catchment area.

With a very high risk of increased frequency of cyclones, there will be increased incidents of floods in the catchment area. Indirectly the surface water bodies would be filled, and aquifers recharged due to additional rainfall from cyclones. Thus, the vulnerability of the catchment to extreme events will be mixed, with more frequent flooding being the main concern.

4.4 Saltwater Crocodile

Bhitarkanika National Park, Odisha, has the largest habitat of the endangered Saltwater Crocodile in India. Brackish wetlands and natural lush green mangroves make for a peaceful abode for crocodiles. The population of crocodiles increased from 1498 in 2008 to 1798 in 2020. The average survival rate of hatchlings is 1% to 1.5%. The life span of Saltwater Crocodiles ranges from 70 years to 100 years. They are opportunistic feeders, preying on a variety of species like crab, fish, birds, turtles, pigs, small cattle, buffalo and wild animals. The usual mating period is from January to March, with nesting commencing in the first week of May.

3.4.1 Impact of Climate change on crocodiles

Climate change will cause several changes to the Bhitarkanika ecosystems that will impact the crocodiles:

- **Changes in geomorphology and habitat of the mangroves:** The impact of climate change within the mangrove habitats, especially the mud banks favoured by adults for basking, is uncertain, with some erosion and some deposition of sediments. Increased rainfall and flooding in the monsoon are likely to cause changes in the available basking habitats. The sea-level rise will tend to reduce these areas within the Ramsar site, so that the crocodiles may seek other basking areas outside the site, leading potentially to human – animal conflict.
- **Changes in food availability and feeding patterns:** If climate change affects the productivity of the mangrove area for fish and crustaceans, the principal natural food items of the crocodiles may become less available, so that the crocodiles will be forced to feed more on domestic species again, resulting in a rise in human – animal conflict.
- **Changes in nesting, hatching and survival of young crocodiles:** The nesting, hatching and survival of young crocodiles is already a risky process. When the juveniles emerge into the environment, with increasing air and water temperatures, their dive duration will be shorter, and they will therefore spend more time basking outside the water and be more exposed to predators.
- **Changes in the gender balance of the crocodile population:** The increasing temperatures during the incubation period (March to July) may change the gender balance in the hatchlings, with more males in the population, especially from those eggs laid in more exposed nests. A shift in the greater number of males in the population will have long-term implications for the viability of the local populations of Saltwater Crocodiles.

4.4.2 Impact of precipitation change

Kendrapada district and especially Rajnagar Block are mapped as a high flood zone area by the state disaster management authority. Increased rainfall (by 3.9%, i.e., 48.2 mm, from 1262.2 mm to 1310.4 mm) by the 2050s during the monsoon season (June – September) will lead to a flooding situation in Bhitarkanika. July is the hatching period of crocodiles, and hatchlings will be exposed to high rainfall.

Being an aquatic creature, an adult crocodile is adaptive to high tides and floods. However, flooding has a significant impact on hatchlings. The mortality of newborn hatchings increases when they are washed into floodwaters as they become prey to aquatic predators such as large fish and adult crocodiles. Erosion of mudflats caused by flooding will lead to a reduction of the basking area for crocodiles. The risk of crocodile attacks on human and domestic cattle will increase as crocodiles enter human habitations during flooding events.

Crocodiles are less vulnerable to decreased rainfall during winter (January – February).

4.4.3 Impact of increased temperature

An average increase in temperature of 2°C is projected by 2050. During the monsoon, the temperature will increase from 31.6°C to 33.5°C, and during summer, the temperature will increase from 33.5°C to 35.6°C. Crocodiles are highly vulnerable to the increase of surface water temperature. Crocodiles are ectotherms – their body temperature is closely tied to the environmental temperature. Young Saltwater Crocodiles will make shorter dives in the water and remain on land for longer, increasing the risk of being attacked by predators[33].

The increased temperature during the incubation period, i.e., during the monsoon, will have significant impacts on the gender determination of hatchlings. More male hatchlings will be produced if the temperature increase is sustained during the incubation period 33°C. If artificial incubation management is not continued, then the gender imbalance will affect the population of crocodiles in the long run.

[33] Acute increase in water temperature results in shorter dive duration (www.ncbi.nlm.nih.gov).

The habitat area of crocodiles will shrink as some creeks become dry. With an increase in temperature during summer, the food intake of juvenile crocodiles may reduce, given the longer periods spent out of the water, which will affect their physical growth.

4.4.4 Impact of extreme events

Crocodiles are highly vulnerable to the sea-level rise as the mudflat areas used for basking and nesting will be reduced. Bhitarkanika is highly exposed to cyclones, which occur mostly during the nesting period of the crocodiles. Yet, the very design of crocodile nests in the ground under Hental mangroves *(Phoenix paludosa)* ensures that they have a low risk of damage[34]. Juveniles are most at risk once they are hatched and in the early stages of development.

Bhitarkanika has a 'moderate' to 'high' risk of storm surges up to 5 m, and the intensity of storm surges is 'high'. As Bhitarkanika Sanctuary is only 2 km away from the coast, the sensitivity to storm surges is 'very high'. Crocodile nests and eggs could be washed out, leading to a reduction in the crocodile population. Juveniles will be washed out of the sanctuary area for a temporary period. In summary, crocodile populations are 'highly vulnerable' to storm surges.

4.5 Olive Ridley Sea Turtles

Olive Ridley Sea turtles form enormous congregations along the Odisha coast during the breeding season (November - April), with nesting taking place along suitable nesting beaches at the Gahirmatha, Rushikulya and Devi rookeries since their discovery in 1974. Gahirmatha is known to be the largest Olive Ridley's rookery in the world. The incubation takes about 60 days, but since the temperature of the sand governs the speed at which the embryos develop, the hatching period can cover a broad range. Essentially, the hotter the sand surrounding the nest is, the faster the embryos will develop. Cooler sand has a tendency to produce more males, with warmer sand producing a higher proportion of females[35]. The hatching occurs between March and April in Gahirmatha and ranged between 100,000 and 800,000 in different years. There were instances of failure of mass nesting in 1997, 1998 and 2008 at Gahirmatha, caused by drastic changes in nesting beach characteristics.

Historically, mass nesting has taken place along the 10 km of mainland coast in Bhitarkanika Wildlife Sanctuary. However, from 1989, nesting became restricted to a 4 km long isolated sand bar projecting into the Bay of Bengal. The super cyclone in 1999 fragmented the 4 km nesting beach into two islets, namely Nasi-I & Nasi-II. The Defence Research and Development Organization (DRDO) have reported that mass nesting now takes place along just a section of a 900 m long beach on Wheeler Island, which is located at the tip of the sand bar – a very exposed area susceptible to change.

3.5.1 Impact of Climate change on Olive Ridley turtles

Climate change is likely to have the following impacts upon Olive Ridley Turtles:

- **Changes in the nesting habitat on Gahirmatha beach:** Already the original nesting beach at Gahirmatha has been reducing in size from 1989 and has been further fragmented by cyclones. The sea-level rise and the increased risk of storm surges and cyclones are likely to have a significant effect on the nesting habitat of the turtles, either through submergence of the suitable nesting areas (sea level rise) or erosion and washing out of turtle nests (storm surges and cyclones). The probable trend with climate change is that the nesting beaches will become smaller and less suitable for the turtles. The turtles will be forced to find other beaches, which also may not be appropriate for the hatching and survival of the young turtles, with a reduction in the overall turtle population.
- **Changes in the gender balance of the turtle population:** The increasing temperatures during the incubation period (February - April) may change the gender balance in the hatchlings, with more males in the population, especially amongst those eggs that are laid nearer to the surface, i.e., in shallower and more exposed nests. A shift in the greater number of males in the population will have long-term implications for the viability of the global populations of Olive Ridley Turtles.

[34] Tropical cyclones have negative short-term impacts on crocodile nesting (www.tandfonline.com)
[35] https://www.conserveturtles.org/information-sea-turtles-general-behavior/

4.5.2 Impact of precipitation change

The increase in rainfall during monsoon (June - October) by 48.2 mm will not have a significant impact on Olive Ridley Turtles as they arrive at the Odisha coast during the post-monsoon season. Neither the sandy beach nor the eggs will be affected by the increase in rainfall. Likewise, the decrease in rainfall during the dry season (February - May) by 13.3 mm will not have a significant impact as temperature is the main determinant for hatching. However, some rainfall during March and April is required to maintain the temperature when the eggs of the turtles are in the rookeries.

4.5.3 Impact of temperature change

Olive Ridley turtles need a temperature of 30°C to 34°C for successful hatching between February and April and thus the increase in temperature (from 33.5°C to 35.6°C) may have a medium impact and result in a shorter incubation period with a chance of exclusive production of a single sex. Hence, the vulnerability to the rise in temperature is medium.

4.5.4 Extreme Events

With a projected sea-level rise of 0.5 m by 2040, there will be high tides at the shoreline and further inland, which will disturb the turtle congregation and mating. There will be a significant reduction in the sandy beach due to erosion of sand dunes, leading to a reduction in the availability of mass nesting areas and in mass nesting activity by the Olive Ridley Turtles. The vulnerability of the turtles to the sea-level rise is ‘very high’.

Similarly, cyclones with severe intensity and frequency during October – December will lead to poor congregation and breeding during the pre-nesting season and damage to the sandy beach further restricting mass nesting.

Storm surge of up to 5 meters will result in high mortality among turtles that are congregated close to the shoreline waiting for breading and mass nesting. Sand dunes and beaches will be eroded, and the beach will be unsuitable for mass nesting of turtles due to mud layers forming on top of the sand. The receding water of tidal waves during the incubation period will wash away eggs from the nesting sites, reducing the number of hatchlings. The vulnerability of turtles to storm surges is ‘high’.

4.6 Fisheries

Fish are a critical component of the Bhitarkanika ecosystems. Any changes in species composition and populations will have far-reaching knock-on effects on many dependent species. For example, fish provide food for half a million migratory waterbirds. Mangrove ecosystems serve as vital nursery grounds for the economically important nearshore fish and shellfish species. People at the Bhitarkanika Ramsar site depend on fishing (freshwater, brackish water and marine) and aquaculture (prawns) for their livelihoods. Yet, during the past decade, fish species diversity and populations of various species have reduced, while fish catch, and effort have increased.

Despite a seasonal ban imposed by the Government of Odisha, illegal river and marine fishing continue in parts of the restricted areas, involving local and distant water fishers. The Forest & Wildlife, Marine Fishery, Inland Fishery, Water Resource and Revenue departments facilitate implementation of the Fishery Act and other laws for the protection of the Ramsar Site, but enforcement often proves challenging.

In the villages, the number of aquaculture ponds has been increasing[36]. The Fishery Department implements various livelihood schemes to promote fish production and marketing within the site. Polluting effluents entering from the catchment into the Ramsar Site water bodies from industries, mining, aquaculture farms, agricultural fields (agricultural chemicals) and domestic sources are impacting fisheries, fish populations and species diversity. Climate change is intensifying those effects.

[36] Cooperation needed from the Fisheries department, Orissa State for controlling prawn culture in an eco-sensitive zone, which would also impact the native fish population due to effluents and excess drawl of water.

4.6.1 Impact of Climate change on fisheries

Climate change is likely to impact the fisheries in the following ways:

- **Changes to the mangrove ecosystem and its productivity:** If climate change and sea-level rise have negative impacts on the mangrove ecosystems, with loss and degradation of mangrove cover and density, the critical role of the Ramsar site as a nursery ground for fish and shellfish will be reduced. This will lead to a fall in productivity of the mangrove ecosystems resulting in falling fish catches within and outside the Ramsar site. Climate change will tend to compound the effects of illegal and overfishing within the Ramsar site.
- **Changes to fish populations and species diversity:** The species mix and size of fish populations in the Ramsar site are likely to be affected most by the availability of freshwater from catchment run-off and rainfall, the overall salinity in the creeks and mudflats, and the increased temperature. The projected increase in salinity will favour more marine species, with the fresh- and brackish water species tending to be displaced. The increased temperatures of the water in creeks and estuarine areas will tend to favour those fish species that are less sensitive to higher temperatures and lower dissolved oxygen levels.
- **Water quality changes:** The likely increasing salinity and temperature of the waters will further decrease the water quality and aggravate existing stresses on fish caused by water pollution caused by sources in the catchment. Water quality stresses may lead to lower survival of juvenile fish and lower fishery productivity and in extreme cases to adult fish kills.
- **Damage and loss of fishing opportunities:** In addition to the lowered fish productivity and fish catches resulted from climate change, the impacts of cyclones and storm surge on fishing livelihoods will be expressed through loss of fishing days and damage to boats and fishing gear.

4.6.2 Impact of precipitation change

The precipitation during the monsoon (June - October) is projected to increase by 3.9% (i.e., 48.2 mm, from 1262.2 to 1310.4 mm). The increase is likely to be concentrated in more intense events bringing more freshwater in the water bodies in short periods, which will improve the conditions for the mangroves, potentially leading to increases in fish numbers. On the other hand, the increased organic material and nutrient load from the catchment in the creeks may lead to eutrophication and fish kills.

The projected decrease in rainfall by 8.2% (i.e., -13.3 mm, from 167.0 to 153.7 mm) during the dry season will mean less freshwater in rivers, creeks, and ponds impacting on fish species and numbers. With decreased water levels, fish will be more easily consumed by dependent birds and animals. Smaller fish numbers and overfishing will have impacts on the livelihoods of local communities. The vulnerability of the fisheries to precipitation reductions in the dry season will be ‘high’.

4.6.3 Impact of temperature change

An overall increase in temperature is projected during all three seasons. Temperature changes can produce shifts in fish and aquatic species composition. Increased temperatures of water bodies would reduce the availability of fish. Increasing ocean acidity will lead to a reduction in zooplankton and affect the availability of marine fish. Overall, drought conditions and reduced water availability will reduce fish populations. The vulnerability will be ‘medium’ during the monsoon and pre-monsoon periods and ‘high’ during the winter period.

4.6.4 Impact of extreme events

The projected sea-level rise of the Ramsar site coastline will reduce the habitat for spawning and growth of marine and brackish water fish. Freshwater fish will tend to be replaced by brackish water fish as the salinity of water increases.

A very high risk of increased frequency of cyclones during October to December will lead to the destruction of fishery habitats and reduced availability of fish. The livelihoods of the communities will be affected by reduced fish catches and damage to

boats and fishing gear.

Storm surges up to 5 m are expected in the area. The saltwater intrusion into aquatic habitats will affect fish diversity, species composition and availability. Overall, the vulnerability of the fisheries to extreme events is ‘high’.

4.7 Tourism

Bhitarkanika is a national park, wildlife sanctuary and Ramsar site. It is a tourist destination of international importance. Tourists are attracted by the lush green mangrove forests, the Saltwater Crocodiles, Asia’s largest mixed-species heronry *(Bagagahana & Matha-Adia),* numerous wild animals and the globally significant nesting beach of the Olive Ridley Turtle (Gahirmatha). The national park is open for tourism from January to April and from August to December. The peak season is from October to February. Annually around 50,000 tourists visit Bhitarkanika.

Tourism is increasing every year. Only the Covid pandemic, in 2020 – 2021, halted that trend. The livelihood activities related to tourism such as restaurants, canteens, lodging, homestays, boating, shops and local guides are increasing. However, tourism in Bhitarkanika is a seasonal and secondary livelihood for a very small population from 20 – 25 villages that are close to the sanctuary area. The growth of the service industries is very slow as many of the tourists who visit prefer other places for overnight accommodation.

Climate change and human activities are adding more risks in the area, affecting tourism. For example, eco-tourism operators do not dispose of garbage safely. At times of heavy rain and flooding, garbage enters the rivers and creeks and blows across the site, causing serious pollution and unsightly conditions.

4.7.1 Impact of climate change on tourism

Climate change is expected to impact tourism at the Bhitarkanika Ramsar site in the following ways:

- **Loss of attractiveness of the Ramsar site for visitors:** If the mangrove ecosystems degrade, with loss of mangrove species diversity, cover and density, as pollution increases, and the numbers and diversity of key species reduce (including crocodiles, migratory birds and turtles), the site will become less attractive for visitors. Visitor numbers will fall, with lower livelihood opportunities for local communities.
- **Reduced access to the Ramsar site:** The increased risk of floods and storms reduce access and safety at the Ramsar site – but this is less of an issue because visits are restricted during the monsoon period (June to September) and when the crocodiles are nesting.
- **Damage to tourism facilities:** The increased risk of cyclones and storm surges may damage tourist services and interpretation facilities and require visits during the peak visiting period (October to February) to be suspended.

4.7.2 Impact of precipitation change

An increase of 3.9% in rainfall during the monsoon (i.e., 48.2 mm, from 1262.2 mm to 1310.4 mm) is projected for the Ramsar site, with a more significant increase of 11.2% or 140 mm in the immediate upstream areas of the catchment. More erratic rainfall in the upper catchment area of the Brahmani could lead to flash flooding from June to September. The tourists’ exposure to increased rainfall and floods is medium as the number of tourism days is limited during the monsoon and restricted for a few days to ensure safe nesting of crocodiles. Tourism has medium sensitivity to increases in rainfall and floods as Bhitarkanika is located on the coast, and flood waters recede quickly. Overall, the vulnerability of the tourism sector to increased rainfall during the monsoon and to the decreases in rainfall during the dry season is ‘low’

4.7.3 Impact of temperature change

A 2°C increase in temperature will impact the natural attractiveness of Bhitarkanika during summer. The sighting of wild animals and crocodiles will reduce, and migratory birds will take an early departure from the wetland, which will limit the bird sighting days during late winter. Yet, the benefits might outweigh the negative impacts as the increase in temperature during the winter periods may prolong the period for tourist visitation.

3.7.4 Impact of extreme events

The impact of the sea-level rise is already visible along the coastline of Bhitarkanika. It will continue to bring significant changes in biodiversity and ecosystem health, reducing the attractiveness of the Bhitarkanika site and its global conservation values. The number of tourists visiting Bhitarkanika would fall. Indirectly, there may be more out-migration of those whose livelihoods depend on tourism in search of work elsewhere. Most of the migrants will be men – leaving their families in Bhitarkanika on a seasonal or long-term basis. That will further increase the work burden of single women and their role in protecting children and maintaining tourism-related livelihoods in the face of future disasters. The vulnerability to the sea-level rise, storm surges and cyclones is ‘very high’. The tourism sector is highly exposed to storm surges. Storm surge causes extensive damage to tourism assets. Tourism will undergo heavy financial losses for the reconstruction and recovery processes. Storm surge is mostly followed by a cyclone.

The peak season for tourism is from October to February, and the exposure to cyclones is ‘very high’. Tourism assets such as boats, petty shops and small restaurant structures are ‘highly vulnerable’ to cyclones due to their designs and location. The post-cyclone reconstruction cost of tourism services will be ‘high’. Tourism days will be suspended for a few days due to the damages of assets and the need for restoration. The adaptation capacity in the tourism sector is low as the practice of micro-insurance is negligible among petty shops and small restaurant operators as is the insurance of people engaged in tourism.

5 ADAPTATION PLANNING

5.1 Summary

Saltwater Crocodiles, mangroves, Olive Ridley Sea Turtles and fisheries are the four most vulnerable assets impacted by the projected climate changes at the Ramsar site and its catchment. Those changes are precipitation increases during the rainy season and decreases during the dry period, overall temperature increases and increases in extreme events including sea-level rise, cyclones and storm surges. The extensive catchment of the Ramsar site and the tourism sector will also be impacted by those changes and the degradation of the overall health of natural systems.

The adaptation options that have been assessed as of ‘high’ and ‘very high’ priority are summarised in this chapter. They need to be implemented as part of the overall site management plan. Ecosystem-based adaptation and nature-based solutions need to be given priority. Research and monitoring of the impacts of climate change will be critical for effective adaptation and continuing adjustment to the changing conditions at the Ramsar Site. 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 is provided in Annex 3).

Adaptation implementation should be integrated into the respective work plans of the following departments: Forest, Environment and Climate Change Department (FECCD), Water Resources Department (WRD), Fisheries and Animal Resources Development Department (FARDD), Odisha Tourism Development Corporation Ltd. (OTDC), Odisha State Pollution Control Board (OSPCB), Panchayati Raj and Drinking Water Department (PRDWD) and the Meteorology Department. Also, Civil Society Organisations (CSOs), research institutions, the private sector and, importantly, local communities have critical roles to play.

5.2 Mangrove habitat

There are 29 true mangrove species and 72 mangrove associates in different mangrove forest sites of Bhitarkanika National Park. The Forest Department has been planting mangroves which has increased forest cover and density in target areas. The baseline shows an increasing trend in salinity at all stations as freshwater flows from the catchment have been reducing due to increased diversion and abstraction for agriculture.

The mangroves provide the habitat for one of the largest heronries in the region. More than 20,000 birds of 11 species nest in this heronry at Bagagahan, in Bhitarkanika, during June – November every year. The impacts of climate change on the heronry will depend on the exposure of the mangrove trees to the sea level rise and whether the tree roots will become permanently submerged and hence die out. The location of the heronry on land that is slightly higher than the more exposed mangrove areas, probably means that the risks from sea level rise will be lower and with a longer time frame. The increased exposure of the heronry to cyclones and storm surges will also be a factor. It is probable that the herons established this heronry in a location that was more protected against strong winds and storm surges, and so a concern would be that the site will be less protected with changing conditions.

Decreased rainfall and increased temperature will contribute to increasing salinity from the Brahamani and Baitarani river basins reaching the creeks of Bhitarkanika. Some mangrove species are sensitive to the increased salinity and will begin to decline and be lost. **Adaptation measures include:**

- Research and surveys of mangrove forest species compositions that change with a saline gradient should be undertaken to understand the sensitivity of various mangrove species and likely outcomes.
- Recharge of maximum rainwater into the aquifer in the mangrove forest area through various rainwater conservation methods such as earthen bunds and subsurface dykes that will dilute the salinity in the subsurface and protect the mangroves from high salinity exposure. An earthen bund and channel are constructed at a suitable location to intercept surface runoff water. A subsurface dyke is a structure that is built in an aquifer to intercept the natural flow of groundwater, increasing the amount of freshwater stored in the aquifer and its level.
- A release of additional freshwater from the catchment especially at times of reduced rainfall is to be negotiated with reservoir managers

The sea-level rise and tidal and storm surges will inundate significant areas of existing mangroves, leading to mortality of trees and rendering gap areas unsuitable for replanting, both along the creeks and in the beachfront areas. Adaptation measures include:

- Identification of mangrove areas most at risk from the sea-level rise and storm surges, including heronry areas
- Establishing saline embankment with green wall fencing along the coast to reduce the impact of sea-level rise and tidal surges in the mangrove forest areas
- Planting more saline-resilient varieties of mangrove in the areas that will not be inundated by the sea-level rise and that are appropriate to Bhitarkanika based on research to maintain the density of the mangrove forest
- Monitoring the mangrove trees around the heronry and, if the area appears to be at risk of sea-level inundation, developing a strategy for encouraging heron nesting in areas where mangroves are more secure in the long term.

Cyclones, which are likely to increase in frequency and intensity, can create large areas of damage to the mangrove forest, felling trees and creating gaps in the forest. Adaptation measures include:

- Planting of short-height mangrove associate varieties to minimise the damage to mangrove forests during cyclones in the Bhitarkanika National Park area
- Replanting gaps in the forest area created by cyclones with appropriate species diversity
- Monitoring the mangroves around the heronry after cyclones

- Empowering communities with training for nursery raising, plantation and maintenance of mangrove forests in a competitive mode. Joint forest management can be undertaken by the community and Forest Departments with fixed accountability.

5.3 Catchment

The Bhitarkanika Ramsar site is in the deltaic region of the Brahmani and Baitarani rivers. The combined basins extend over 51,822 km^2 and have a fundamental influence on the downstream site through the hydrological control of over 42 dams, and the operation of extensive irrigation systems, industry and settlements. The mangrove ecosystem and creeks are dependent on freshwater and clean water flows reaching Bhitarkanika to maintain the saline balance and water quality.

Increasing rainfall: During the monsoon period, the rainfall in the catchment will increase, though it will decrease in the hotter pre-monsoon and post-monsoon seasons. Adaptation measures include:

- Negotiating a share of the increased freshwater in the rivers to reach Bhitarkanika to maintain the site hydrology and mangrove ecosystem
- Ensuring optimum environmental flows in rivers and streams, and active storage in the water bodies through ecosystem-based management of reservoirs
- Applying water demand management approaches to provide for drinking and ecosystem services; involving water use efficiency and equity, and seeking wetland ecosystem rehabilitation and health
- Scheduling irrigation so that it adheres to the principles of efficiency and conservation and involves reviews and innovation in irrigation systems to reduce wastage and excess

Increased rainfall and sediment transport during the monsoon will increase soil erosion and the sediment reaching the creeks in Bhitarkanika, causing sedimentation issues, blockage of some creeks and smothering of some areas. Adaptation measures include:

- Improved watershed management to control soil erosion and trapping of sediments before they reach the drainage systems and rivers

More frequent and more intense rainfall causing flood events in the catchment, which will arrive at Bhitarkanika and cause damage to both forests and property. Adaptation measures include:

- Comprehensive cumulative assessment of existing and planned catchment development projects to ensure they are designed according to ecosystem-based adaptation principles and integrate nature-based measures to control the intensity of floods and lessen damage
- Monitoring the hydrology of the basin to better inform management and development controls

Water pollution with increased rainfall and floods. Pollution from various large industries, agricultural runoff and domestic wastewater in the catchment is already creating water quality problems within the Bhitarkanika Ramsar site. This increasing contamination influences the growth and health of mangroves and aquatic organisms and the terrestrial animals dependent on them. Increased rainfall and floods during the monsoon period are likely to wash more pollutants from the catchment into the creeks and mangroves, while droughts can concentrate pollutants that are already within the mangrove ecosystem. Adaptation measures include:

- Compliance and more effective monitoring and enforcement of all laws with the implementation of measures to prevent water pollution from the respective sources, especially industry and agricultural landscapes
- Creating awareness and capacities amongst communities and the private sector to prevent pollution, including plastic and solid waste, through effective treatment and management

5.4 Saltwater Crocodiles

Bhitarkanika National Park of Odisha has the largest habitat of the endangered Saltwater crocodile in India. Brackish wetlands and mangroves make the ideal habitat for crocodiles. The average survival rate of hatchlings is 1% to 1.5%, while life span ranges from 70 to 100 years.

The projected increases in temperature in all seasons, but especially in the hot pre-monsoon period, is likely to affect the metabolism and comfort of the crocodiles. While the projected increases will not exceed the 'comfort zones' of crocodiles, protection and adaptation measures include:

- Maintenance of the density of mangrove cover along the Khola Creek, which will reduce the temperature of the creeks and keep a more balanced temperature for optimal crocodile health
- Expanding and maintaining the crocodile habitat to limit the presence of crocodiles outside the forest and the possibility of human–crocodile conflict
- Regular excavation of the sub-creeks to maintain the water level required for crocodile habitation

Increasing temperature: The breeding and nesting of crocodiles are likely to be influenced in several ways by the increased temperature. Adaptation measures include:

- Ensuring that Hental, mangrove associate plants continue to grow in abundance at Bhitarkanika. The availability of Hental leaves, which the crocodiles use for covering the eggs in their nests, may decrease
- Artificial rearing of crocodile hatchlings in hatching centres for up to four years should be facilitated by the Forest Department to reduce the mortality among the hatchlings and maintain an appropriate gender balance in the population. Increased temperatures in the incubation of the eggs lead to single-sex selection amongst hatchlings, which can distort the gender balance in the population. There is already high mortality amongst the hatchlings, and this will be increased by rising temperatures

Extreme events: As with other species, extreme events such as cyclones and tidal surges can wash crocodiles out of their preferred habitats and cause damage and mortality, especially among young crocodiles.

- Careful monitoring, maintenance and planting of mangroves along the river and creek sides will protect crocodiles from extreme events such as cyclones and tidal surges
- Awareness generation of community members and fishers on coordination and response mechanisms will also protect the crocodiles washed out of the mangrove area during flooding and tidal surge situation

5.5 Olive Ridley Sea Turtle

Gahirmatha is known to be the largest Olive Ridley rookery in the world. Olive Ridley Sea Turtles form enormous congregations along the Odisha coast during the breeding season (November - April), with nesting taking place along suitable nesting beaches at the Gahirmatha, Rushikulya and Devi rookeries. Mass nesting now takes place along a section of a 900 m long beach on Wheeler Island. The hatching occurs in March and April at Gahirmatha. Estimates of the annual turtle nesting have ranged between 100,000 and 800,000 in different years. Incubation takes about 60 days.

The sex of the turtles and crocodiles is determined after fertilisation. The temperature of the developing eggs is what decides whether the offspring will be male or female. If a turtle's eggs are incubated below 27.7°C, the turtle hatchlings will be male. If the eggs are incubated above 31°C, the hatchlings will be female. Temperatures that fluctuate between the two extremes will produce a mix of male and female baby turtles. The warmer the sand is, the higher the ratio of female turtles will be. Increased temperatures could result in skewed and even lethal incubation conditions, which would significantly impact turtle populations.

Projected increases in temperature during the incubation period (November - April) are likely to increase the stress levels on turtle populations. Needed adaptation responses are:

- Regular monitoring of the temperature at the mass nesting beaches during the incubation period (March and April)
- Providing shade to the rookeries to maintain an appropriate temperature for the development of embryos
- Spraying water from the sea on the rookeries to maintain the temperature
- Training staff members and volunteers (e.g., Eco-development Committees and community members) in best practices for Olive Ridley Turtle monitoring and management
- Deployment of trained staff members and volunteers during the incubation period for protecting eggs and hatchlings from predators
- Maintaining a database of trained volunteers and developing and coordinating a programme of volunteer support

The sea-level rise, cyclones and storm surges can damage or destroy nesting beaches or make them unsuitable for nesting. Needed adaptation responses include:

- Conducting a research and survey programme to understand beach conditions and suitability for nesting
- Repairing and maintaining the nesting beach, making sure it is suitable before mass nesting
- Installing temporary cordons/fencing on the outer boundary of the nesting sites to protect the eggs and hatchlings from predators
- Initiating a programme of artificial hatching in the nearby natural beaches
- Conducting a study to assess the extent to which cyclones are affecting Olive Ridley Turtles during the congregation and mating period in the sea
- Clearing the mud layers after storm surges and cyclones from the top of the beaches and sand dunes of the nesting beach to ensure they are suitable for mass nesting
- Rearranging the rookeries and relocating eggs to continue the incubation process in case there is a tidal surge
- Deploying volunteers to provide a sand cover to the eggs when the sand layer is washed away
- Conducting regular clean-ups involving volunteers to reduce plastic waste and other debris on the nesting beach

In the medium term, soft and even hard measures may be required to sustain the nesting beaches. Great care is required with any intervention to influence sand accumulation because some measures such as groynes or offshore breakwaters could impact negatively on turtle access and use. As a start:

- Conduct research to better understand the key processes and characteristics of coastal dynamics and system boundaries that reflect the erosion problem
- Define the available soft and hard options and provide technical information such as the design, materials to be used, construction methods and maintenance and cost – benefit analysis

5.6 Fisheries

Mangrove ecosystems serve as vital nursery grounds for the economically important nearshore fish and shellfish species. People in the Bhitarkanika Ramsar site depend on freshwater, brackish water and marine fishing and prawn aquaculture for their livelihoods. Fish are the food for the migratory waterbirds of the Ramsar Site. The fish species diversity and populations of some species have reduced although fish catch has increased in recent years due to increased effort.

Various adaptation measures are needed to reduce the threats that the increasing salinity and pollution pose to fish and to the mangrove and creek habitats:

- Negotiating additional releases of water from upstream reservoirs during the dry season (February - May) to increase the freshwater flows into the rivers and creeks to reduce salinity levels in the wetland
- Collaborating with the Odisha State Pollution Control Board and other relevant agencies to ensure compliance with standards for all the sectors causing pollution

- Working with the Odisha State Pollution Control Board in initiating a programme of regular monitoring and testing of pollution levels at the Ramsar site
- Sharing the sanctuary boundary demarcation with line departments and communities and create awareness to avoid encroachments
- Introducing a rigorous control system for granting permissions for freshwater aquaculture in the buffer zone and discouraging brackish water aquaculture
- Working with the Fishery Department to conduct awareness programmes among the community members, especially women, on various freshwater fish-farming methods and species to promote alternative livelihood options
- Building on current programmes to regenerate the mangrove habitat (plantation, protection, and conservation) and managing creeks and distributaries (such as desilting)

5.7 Tourism

Tourism-based adaptation measures should aim to protect and improve the attractiveness of the natural features of the Bhitarkanika mangroves as well as improve the tourism facilities and activities in and around the area. The sea-level rise, cyclones and storm surges present the greatest climate change threats. Adaptation measures include:

- Conducting site-specific assessment to identify areas which will be submerged by sea-level rise and storm surge in future time slices and introduce development controls and appropriate protective measures for those areas including identifying remaining areas suitable for replanting mangroves and for development of tourism facilities. A detailed Ramsar site spatial plan with zoning and linked safeguards taking climate changes into account are required.
- Developing protection measures in and around existing tourist places that would be affected by the sea-level rise – and a medium-term adjustment programme for their relocation. In the meantime, dykes may be needed to protect key tourism assets.
- Planting mangroves above the new submergence zone so that the wildlife can progressively shift to the new areas with suitable habitats
- Conducting surveys to identify vulnerable bird nesting areas and sites and ensure their protection by enrichment planting of mangroves in those areas
- Introducing other tourism activities in the newly submerged areas such as boating, creating watch towers and floating restaurants, and deploying houseboats at Hukitola or Dhamara, but ensuring that the necessary environmental standards for effluents and solid waste management are enforced
- Training tourist guides in nature and conservation practices and monitoring to ensure that standards are maintained
- Upgrading the interpretation signage and communications material to enhance the touristic experience and awareness
- Creating awareness among tourism operators on the insurance of various assets such as boats, hotels and petty shops that may be susceptible to damage during extreme events
- Improving and restoring the communications systems within Bhitarkanika and maintain the networks of roads and paths.

5.8 Bhitarkanika research and monitoring programme

5.8.1 Survey

Regular surveys are needed to collect data on the biological, chemical and physical features of the Bhitarkanika mangroves site, its habitats and species, reflecting the ecological condition of wetland or key indicators of stress that may influence conservation values. 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 conducted.

5.8.2 Research

There has been a more comprehensive research programme on the Bhitarkanika mangroves compared with some other Ramsar sites in India. This valuable source of scientific information should be put to good use as a foundation for developing a better understanding of the Bhitarkanika wetland ecology in a systematic way, and its responses to climate change pressures, and the needs of the endangered and threatened species and their habitats.

The Bhitarkanika Management Plan describes the extended research studies that have been carried out on Saltwater Crocodiles and Olive Ridley Sea Turtles and have provided insights for their management. Other species to be studied are the Indian Cobra *(Naja naja)*, White-rumped Vulture *(Gyps bengalensis*), White-bellied Sea-eagle *(Haliaeetus leucogaster),* Indian Skimmer *(Rynchops albicollis)* and Common Water Monitor *(Varanus salvator)*.

5.8.3 Monitoring

A comprehensive monitoring programme is urgently required for the Bhitarkanika Ramsar site and the freshwater sources from the catchment on which it depends. Currently, all trends are indicating that the wetland will be fundamentally transformed in the decades to come with losses of biodiversity and its scientific, cultural, touristic and livelihood values. A consistent, thorough and timely wetland monitoring, and assessment programme is needed to halt and reverse those trends, and to better manage and protect the wetland resources. An effective monitoring programme allows managers to establish a baseline for the wetland's extent, condition and functions; to detect changes; to characterise trends over time, and then to respond with appropriate adaptation measures.

Research, surveys and monitoring are fundamental to the detailed design of adaptation measures, for their effective implementation and for the overall adaptive management of the Ramsar site. As a first step, some of the information gaps about the site need to be filled.

The structure of the monitoring programme should include:

- Long-term measurement of climate parameters and extreme events, including local air temperatures, maxima and minima, rainfall, humidity and wind speed and direction.
- Monitoring the hydrology and water quality of the catchment, including freshwater flows into Bhitarkanika from the wider Brahmani and Baitarani River catchments. This should be compared with modelling of the water that is required and might be available to the site after balancing with the upstream demands for water.
- Monitoring of the habitat conditions within the Ramsar site, including:
  - Water quality in the creeks, with a focus on temperature, salinity, dissolved oxygen, suspended solids and turbidity and nutrients and phytoplankton dynamics. Routine monitoring sites should be confirmed so that time series of water quality changes can be built up.
  - Condition of mangrove forests at selected sites representative of the different types and areas of the Ramsar site, e.g., the mangroves at the back, the mangroves fringing the creeks, and the mangroves exposed to coastal erosion pressures. Monitoring should include the mangrove species composition, sizes and health of the trees, and any larger changes in the plots, e.g., loss or damage to trees from cyclones and storm surges.
  - Condition of other important habitats for key species, such as the crocodile nesting areas and availability of Hental, the condition of turtle nesting beaches and the resident bird nesting areas, e.g., the heronry.
- Monitoring keystone species populations, including crocodiles, Olive Ridley Turtles, migratory and resident birds, fish and crustacea populations in the creeks and inundated mangrove areas. Censuses of key species should be carried out routinely every year.
  - For crocodiles, the nesting success and gender specification of juveniles should be monitored each year. In the event of a cyclone or storm surge, the extent to which crocodiles move into other areas outside the Ramsar site and
  - become the subject of human/crocodile conflict should be monitored.

- For Olive Ridley Turtles, the mass nesting events should be monitored closely, and the correlation with climate events, and the conditions of the nesting beaches should be investigated. Research will be needed into the optimum nesting conditions of the beaches and the extent to which these can be recreated after extensive storm damage and erosion of existing sites.
- For the heronry and nesting sites for resident bird species, the habitat conditions of the mangrove forest should be observed each year to ensure that climate events do not damage these locations and that suitable alternatives can be developed in the event of loss of these habitats.
- For the fish and crustacean species that are dependent on the mangroves for spawning and nursery areas, routine monitoring of the adults and juveniles present in the mangrove areas should be carried out at an appropriate time of the year.

o Monitoring tourism numbers, surveys of tourism facilities and visitor experiences will help improve the designs of the facilities and activities at Bhitarkanika. The impacts of tourism on the Ramsar site, can include encroachment, effluents and water pollution, solid waste disposal, and disturbance to wildlife. The extent of damage to facilities from cyclones and other climate events should also be monitored.

o 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 the adaptation measures by identifying areas and habitats where the adaptation measures will be implemented and then keeping track of their effectiveness. Once put in place, monitoring can show if the impacts of negative influences and changes are reduced, if keystone species populations are recovering and thriving, if habitats are healthy and the water quality 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 STAKEHOLDER ENGAGEMENT

6.1 Stakeholder engagement in integrated management of the Ramsar site

A broad range of stakeholders need to be involved in the implementation of the Bhitarkanika adaptation plan as part of the overall site management plan. Stakeholder engagement is necessary to successfully achieve priority adaptation measures and for effective decision making through partnerships, awareness, effective communications, and knowledge sharing. A summary of adaptation strategies for site managers is presented in Annex 4.

There are various levels of stakeholder's engagement with different levels of interest and influence as shown in Figure 17. At the highest level, stakeholders need to work together and partner in the implementation of the adaptation measures. If their interest remains high, collaborators with lower influence will be consulted and engaged to the extent feasible. If a particular stakeholder group's level of interest is low but their influence is high, the engagement strategy will rely on discussion, negotiation and compromise. There are key groups whose interest needs to be nurtured and encouraged, such as research groups and NGOs. Other less influential but important stakeholders such as community groups and tourism operators will need to be included in the adaptation measures, their capacities enhanced, and incentives provided for patterns of behaviour that support effective site conservation.

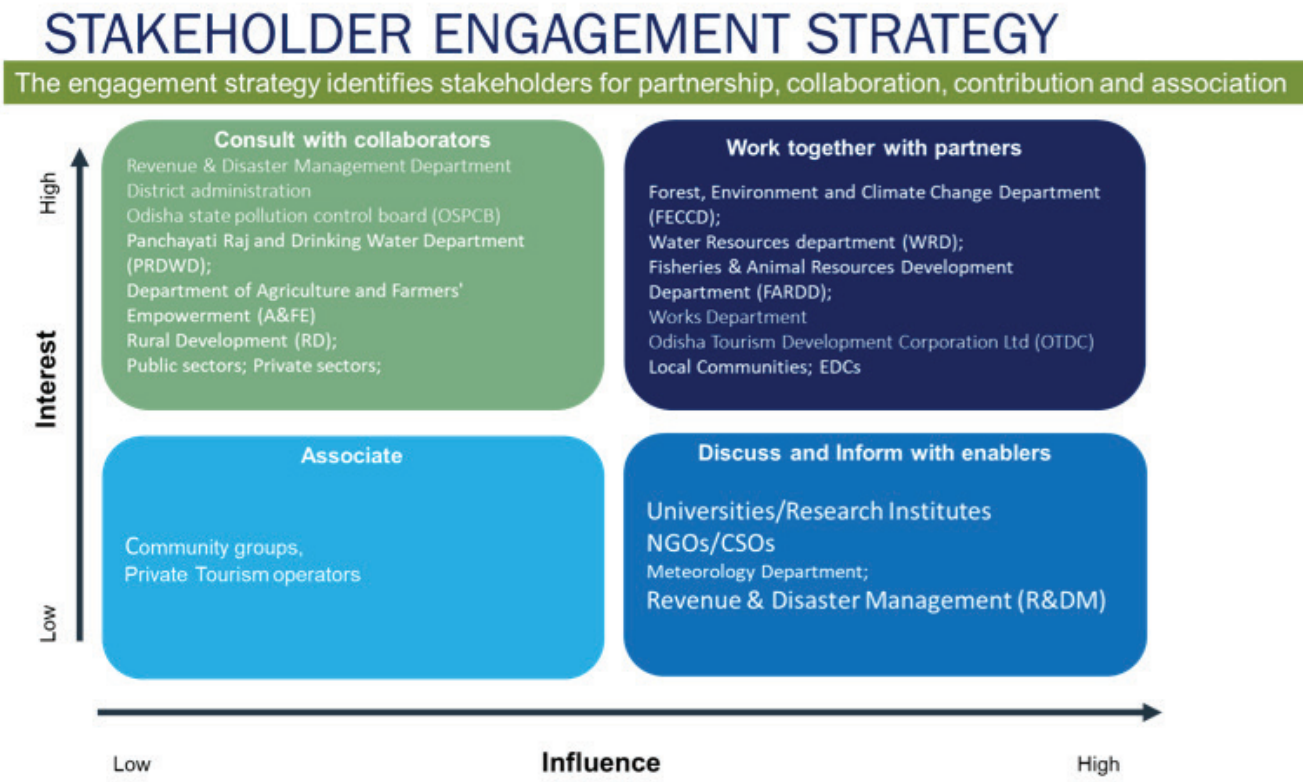

Figure 17 *Stakeholder engagement strategy at Bhitarkanika Mangroves*

There are a few existing coordination mechanisms involving stakeholders that provide opportunities for more effective engagement in Bhitarkanika management. They are implemented by state/national governments in the form of programmes and projects, according to policies, development plans, bilateral development projects, interests of public sectors, and private sectors, and local CSOs. These existing platforms need to be assessed for their potential to bring in stakeholders in a unified way to focus on Bhitarkanika's conservation needs. Some will not be appropriate – others may be promising.

6.2 Conflicts of interest to be resolved

Within the stakeholder groups of Bhitarkanika, some potential policy contradictions have become evident due to different departmental priorities and mandates as shown in Table 15. These conflicts of interest need to be addressed and resolved. Otherwise, they will tend to undermine the Bhitarkanika adaptation effort.

Table 15 *Examples of stakeholder's issues and challenges based on their priorities*

Aspect	Priority	Issues/Challenges
Water storage and release by Water Resources Department	The priorities are mostly for irrigation to sustain agriculture and hydropower projects.	The storage of water in reservoirs will affect the siltation and salinity in the Ramsar Site, thereby affecting the species' existence and diversity.
Developments in the catchment area promoted and managed by the agencies responsible for industry, mining, transport and agriculture	Industries, mining, roads, communication, chemical agriculture, urbanisation leading to pollution of air, water and soil	Developments in the catchment area can impact the Ramsar site negatively, which is located at the tail end of the rivers, i.e., the deltaic region, and receives pollutants from upstream.

Aspect	Priority	Issues/Challenges
Fisheries development	The aquaculture and prawn culture promoted for the livelihoods leading to pollution of water bodies and excess drawing of water	Expansion of the aquaculture ponds in the periphery around the Ramsar site can encroach upon the area. Pollution and drainage water from the aquaculture ponds can affect the water quality and conditions for the wildlife.

The Planning and Convergence Department has emerged as one of the major nodal departments of the Odisha State Government. This department plays a vital role in evolving effective and sustainable short-term and long-term strategies for the overall development of the state. This department prepares policy frameworks for development and is also responsible for coordinating the efforts of different Development Departments relating to:

- Five-year plans, annual plans
- District and regional plans
- State Planning Board
- Issuing of general guidelines regarding formulation and implementation of developmental programmes at the district level
- Coordination and analysis of data required by the government in the execution of the economic and social policy and interpretation of statistics
- Encouraging and aiding departments in taking up more and more projects in the PPP route and providing the necessary support for the purpose

The Planning and Convergence Department needs to be closely involved in resolving issues that undermine the effective management of the Ramsar site and which are beyond the site management agencies to address.

6.3 Strategies for improving stakeholder engagement in Bhitarkanika adaptation

The Bhitarkanika Ramsar Site, under the Forest, Environment and Climate Change Department, could coordinate with various other stakeholders through partnership agreements, MoUs, sharing of data and capacity development. Various methods for improving stakeholder engagement include:

- Participatory planning
- Focus group discussions (FGDs)
- Workshops
- Community-level meetings
- Conference calls (video/audio)
- Paper/email correspondence and provide information, education and communication (IEC) material
- Sharing of study reports, survey information, research data and publications for decision support
- MoUs, agreements and convergence of programmes
- Monitoring and reporting
- Coordinated and managed volunteer programmes

Tables Table 16 - Table 18 show the responsibilities for implementing the different adaptation options and integration into the management plans of the respective stakeholders. The details of adaptation plans and stakeholder responsible, geographical focus, periods and the mode of implementation are proposed.

Table 16 *Stakeholder engagement in integrated management plan/adaptation implementation (off-site)*

What	Who	Where	When[37]	How
Ensuring freshwater flows to the wetland				
Release of water from reservoirs upstream during the dry season (February – May) to ensure minimum flows for increasing the freshwater flows into the rivers and creeks for reducing the salinity in the wetland	WRD, A&FE in consultation with FECCD	From catchment area into the Ramsar site	All	Coordination and agreements, and implementation
Recharge of maximum rainwater into an aquifer in the mangrove forest area through various rainwater conservation methods such as earthen bunds and sub-surface dykes will dilute the salinity in the subsurface.	FECCD	Within Bhitarkanika Ramsar Site	All	Preparing work plans and implementation
Saline embankment with green wall fencing along the coast will reduce the impact of the sea-level rise and tidal surges.	WRD, R&DM, P&C and FECCD	Along the coastal area adjoining the Ramsar Site	LT	Implementation
Introduction of suitable freshwater fishes tolerant to increases in salinity	FARD and FECCD	In the water bodies of the Ramsar site	ST/LT	Research and Consultation with FECCD before implementation
Catchment management				
Water use efficiency and irrigation scheduling should be planned and implemented as per the water availability to ensure the water for drinking and ecosystem services.	WRD, A&FE in consultation with FECCD	From catchment area into the Ramsar site	All	Implementation and policies
The existing irrigation and catchment area development projects and planned future projects and monitoring of the hydrology of the basin and management will control the intensity of the flood and lessen the damage.	WRD, Research Institutes, Meteorology Department	Catchment area and more focus on Ramsar Site.	ST/LT	Implementation
Pollution control				
Control Board norms for all the sectors causing pollution	OSPCB	Catchment area, especially monitoring all water bodies	ST/LT	Compliance of laws by all stakeholders
Create awareness among communities to prevent pollution	OSPCB and FECCD	Catchment area and most importantly in the Ramsar site	All	Programs with communities through CBOs.

[37] Immediate – IM (within the next year), short-term ST (over next 2 years), long-term LT (over the next 10 years)

Table 17 *Stakeholder engagement in integrated management plan/adaptation implementation (on-site)*

What	Who	Where	When	How
Habitat restoration and management				
Demarcation of the sanctuary area and national park needs to be shared among line departments and community and awareness created to avoid encroachments	FECCD and R&DM	Ramsar site area, including sanctuaries, national parks and buffer zones	IM	Remote sensing, DGPS, total station and GPR data
Ecosystem-based adaptation and nature-based solutions to be given priority	FECCD	Ramsar Site area	ST/LT	Planning and implementation
Develop mangroves above the submergence zone so that the wildlife shifts to the new protected areas.	FECCD	Sanctuaries and national parks	All	Planning and implementation
Identify the vulnerable nesting areas and ensure protection of the birds nesting sites by improving the mangroves in the area.	FECCD	Sanctuaries and national parks	All	Planning and implementation
Regular excavation (desilting) of the distributaries, creeks and sub-creeks for maintaining the water level required for crocodile habitation.	FECCD and WRD	Ramsar Site and mainly in the sanctuaries and national parks	All	Planning and implementation
Activities to regenerate the mangrove habitat (plantation, protection and conservation)	FECCD	Sanctuaries and national parks	All	Planning and implementation
Repair and maintenance of the nesting beach, making it suitable before the mass nesting of the sea turtles	FECCD	Sanctuary beach areas	All	Planning and implementation
Clearance of the mud layers (after a storm surge) from the top of the sand/sand dunes of the nesting beach to make it suitable for the mass nesting of sea turtles	FECCD	Sanctuary beach areas	All	Planning and implementation
Species support and management				
Mangrove species are sensitive to increased salinity. Plantation of a better saline-resilient variety of mangrove	FECCD	Sanctuaries and national parks	All	Planning and implementation
Protection of crocodiles from increased temperature can be ensured through maintenance of density of mangroves along the Khola Creek. Artificial rearing of crocodile hatchlings by the Forest Department	FECCD	Sanctuaries and national parks	All	Planning and implementation
Provide shade or spray/sprinkle water from the sea on the turtle rookeries to maintain the appropriate temperature for the development of embryos.	FECCD	Sanctuaries and national parks	All	Planning and implementation

What	Who	Where	When	How
Deployment of trained staff members and volunteers during the incubation period of turtles for the protection of eggs and hatchlings from predators. Installation of temporary cordons/fencing in the outer boundary area of the nesting sites to protect the eggs and hatchlings from predators. Rearrange the rookeries and place the eggs to continue the incubation process in case of tidal surges. Deployment of volunteers to provide a sand cover to the eggs from which the sand layer is washed away. Artificial hatching should be implemented.	FECCD, EDCs, CSOs	Sanctuaries and national parks	All	Awareness, training, infrastructure created and implementation
Species support and management				
Community forest management can be undertaken by communities with support from the Forest Department.	FECCD, EDCs and local communities	Sanctuaries, national parks and buffer zones within the Ramsar site	All	Awareness, Training, Infra-structure created, and implementation
Awareness generation among community members on information and coordination mechanism that will protect the crocodiles trespassing into human habitats during flooding and tidal surge situations	FECCD, EDCs and local Communities	Sanctuaries, national parks and buffer zones within the Ramsar site	All	Awareness, Training, and implementation
Create awareness among the community members, especially women, about various freshwater fish-farming schemes of Fishery Department for alternative livelihood options.	FECCD, FARD, EDCs and local communities	Outside sanctuaries, national parks and buffer zones within the Ramsar site	All	Awareness creation and inclusion in relevant schemes
Innovate other means of tourism in the submerged areas (increase boating, create watch towers, create floating restaurants, and house boats at Hukitola or Dhamara).	FECCD, OTDC and local people dependant on tourism	Ramsar site	All	Planning and implementation
Training to be provided to the tourist guides on nature and conservation practices to facilitate tourists professionally. Also, they should be facilitated for alternative sources of income to cope with lean periods and reduced tourists.	FECCD, OTDC and local people dependant on tourism	Ramsar site	All	Planning and implementation
Create awareness among tourism operators on insurance of various assets susceptible to damage during extreme events and build insurance systems to protect the tourism assets (boats, hotels, petty shops, etc.)	FECCD, OTDC, R&DM and local people dependant on tourism	Ramsar site	All	Planning and implementation

What	Who	Where	When	How
Restore the communications and maintain roads.	Communications (Government/Private) and WD; With in Sanctuaries and National Park by FECCD	Ramsar site	All	Planning and implementation
Addressing Sea-level rise				
For the sea-level rise threat, the release of water from reservoirs upstream will increase the freshwater flows into the rivers and creeks which will reduce the salinity in the wetland and also build dykes as a protection measure.	WRD, WD, A&FE	Catchment area management and focus on impacts on Ramsar Site	ST/LT	Agreements, planning and implementation
Protection against extreme events				
Priority should be given for plantation of short mangrove associate varieties to minimise the damage to the mangrove forest during cyclones.	FECCD	Ramsar site	All	Planning and implementation

Table 18 *Stakeholder engagement in monitoring, surveys and research*

What	Who	Where	When	How
Research/study on mangrove forest species composition that changes with a saline gradient can be undertaken	Universities/ Research Institutes, FECCD	Ramsar Site	IM/ST	Monitoring data through studies and research
Regular monitoring of the temperature of the mass nesting beach of turtles during the incubation period (March –April)	Universities/ Research Institutes, FECCD	Marine sanctuary	All	Monitoring data through studies and research
Capacity Building of the staff and volunteers (EDC/Community members) on best practices of Olive Ridley Turtle monitoring and management.	FECCD, EDCs	Marine sanctuary	All	Capacity building
A study should be undertaken on the cyclones' impact on Olive Ridley Turtles during the congregation/mating period in the sea.	Universities/ Research Institutes, FECCD	Marine sanctuary	All	Monitoring data through studies and research

Stakeholders who are already engaged in the vulnerability assessment and adaptation planning process and who are critical for the effective integrated management and adaptation planning for the Ramsar site:

- Forest, Environment and Climate Change Department (FECCD)
- Chilika Development Authority (CDA)
- Water Resources Department (WRD)
- Fisheries and Animal Resources Development Department (FARD)
- Department of Agriculture and Farmers' Empowerment (A&FE)
- Revenue and Disaster Management (R&DM)
- Odisha Tourism Development Corporation Ltd. (OTDC)
- Odisha State Pollution Control Board (OSPCB)
- Rural Development (RD)
- Panchayati Raj and Drinking Water Department (PRDWD)
- Planning and Convergence Department, Government of Odisha (P&C)
- Wetland Research and Training Centre (WRTC)
- Meteorology Department
- Organisations/CSOs
- Research institutions
- Public sector
- Private sector
- Local communities

6.4 Stakeholders consulted during the first mission

During the vulnerability assessment, the stakeholders consulted twice in the field are detailed below:

Communities:

- Meeting with fisherman/farmer community – Village Subarnapur, Bhanja Prasad and Rangani Village
- Pond aquaculture farmers – Junus Nagar Village
- Fisherman, Talachu fish landing Jetty

Community-based organisations:

- Eco-development Committee, Dangamal
- APUA (NGO)

Government Agencies:

- District Forest Officer, Rajnagar
- Forest Ranger, Bhitarkanika National Park
- Senior Fisheries Technical Assistant (SFTA), Marine Fishery, Rajnagar
- Marine Police, Talchau
- Chilika Development Authority – Executive Director and a scientist
- District Fisheries Officer (DFO), Kendrapara
- Deputy Director Agriculture, Kendrapada district, Odisha
- Assistant Executive Engineer, Embankment Management, Department of Water Resource, Aul, Kendrapada, Odisha
- Junior Engineer, Rural Water and Sanitation Services (RWSS), Patamundai, Kendrapara
- Junior Assistant, Marine Fisheries, Kendrapara

Private agencies:

- Eco-tourism operator, Kanika Sundari

During the first field mission the consultation with stakeholders identified the target assets for vulnerability assessment under these categories: physical infrastructure; key habitats; keystone species; wetland species important for ecosystem services; prioritised the assets based on scoring of the criterion: representativeness; ecological significance; Ramsar importance; sensitivity to change; non-climate threats and availability of data. Six assets were identified: Saltwater Crocodiles, Mangroves, Olive Ridley Sea Turtles, Fisheries, Catchment and Tourism. They are impacted by the climate change threats of precipitation increase during the rainy season and precipitation decrease during the dry period, overall temperature increases and increase in the extreme events such as sea-level rise, cyclones, and storm surge.

The stakeholders were consulted on the vulnerability assessment and development of adaptation priorities for finalisation of adaptation plans for implementing the components in the existing work plans and integrating them into the future management plans of respective agencies.

6.4.1 The stakeholders consulted during the second field mission

Communities:

- Pond aquaculture farmers – Junus Nagar Village

Community-based organisation:

- Eco-development Committee, Dangamal

Government agencies:

- DFO, Rajanagar
- Fishery Department, Kendrapara
- Range Officer, Dangamal
- Odisha Coast Guard, Paradip
- Tahashildar, Revenue Department, Rajnagar

Private agencies:

- Tourism operator, Dangamal

The components of the plans on-site and off-site to be implemented immediately or short-term (over next 2 years) or long-term (over the next 10 years) were finalised. Adaption implementation and monitoring of effectiveness are critical for the management of the Ramsar site, for which stakeholder engagement is most important.

7 CONCLUSION

This report provides an assessment of the vulnerabilities of the Bhitarkanika Ramsar site and its key assets to the projected climate changes of increased rainfall in the monsoon period, and decreased rainfall in the dry seasons, coupled with general increases in temperature throughout the year. The assessments show that these changes in seasonal climates will be exacerbated by the sea-level rise and the increased frequency and intensity of extreme events of cyclones and storm surges.

The increasing salinity and siltation of the creeks throughout the mangrove area will become worse with decreasing rainfall in the dry and hot seasons and will lead to further degradation of the habitat with loss of some of the more saline-sensitive mangrove species and associates. With climate change, the upstream demand for irrigation water and domestic water supply in the catchment is expected to increase, with implications for a decreased flow of freshwater into the mangrove area from the rivers. Flooding during the monsoon is likely to bring more sediment from the catchment into the creeks, increasing siltation and blocking of the tidal exchange necessary for the good health of the mangroves and the flora and fauna in the creeks, including the crocodile habitats.

The existing conditions of high salinity and high levels of pollution from industries and agriculture in the catchment flowing into the water and sediments of the creeks are adding stress to the habitats and the key species assets (fish and crocodiles), in turn threatening the livelihoods of the fishing communities and those dependent on eco-tourism. Increasing temperatures can affect the nesting habits of the crocodiles and the gender balance of the hatchling Olive Ridley Turtles. Extreme events such as cyclones and storm surges have cleared gaps in the mangrove forest, and these events are expected to become more intense and frequent, further degrading the forests. The sea-level rise will permanently inundate some stands of mangroves so that they will die off, but other areas will become tidally inundated and be suitable for mangrove growth in the future. The sea-level rise and storm surges are also expected to threaten the nesting beaches of the turtles.

A range of adaptation measures are presented as options for dealing with these issues, some of which are already included in the current management plan for Bhitarkanika Mangroves. This climate change assessment serves to reinforce the need for these management measures to be carried out with due care and attention, addressing the salinity increases within the area by ensuring the flow of freshwater from the catchment and establishing rainwater storage for groundwater recharge within the mangrove area, and desilting of the creeks to facilitate tidal exchange which is necessary for mangrove health. Mangrove replanting has long been an important management strategy which needs to be continued to fill gaps caused by cyclones, but also to afforest blank areas that will become suitable for mangroves as the sea level rises. The pollution from the catchment is also a concern. Wastewater and solid waste treatment in the catchment will become more important with climate change to reduce the stresses of poor water quality and solid wastes in the creeks. The key species (Saltwater Crocodile and Olive Ridley Turtle) will require specific adaptation measures to maintain the nesting habitats and beaches and keep them cool in the face of increasing temperatures, even using artificial incubation and hatching techniques.

The feasibility and planning of these proposed adaptation measures will require appropriate surveys, research and design, followed by ongoing monitoring and reporting on results to ensure effectiveness. Implementation of all or some of these measures will need the coordination and cooperation of the different stakeholders involved with Bhitarkanika. There are several stakeholders with potentially conflicting development policies such as the Water Resources Department and Fisheries Department. This issue will need to be resolved in order to implement adaptation measures comprehensively. A coordination platform under the Forest, Environment and Climate Change Department, with the assistance of the Odisha State Planning & Convergence Department, is recommended for identifying the measures that should be implemented across all relevant sectors over the next decade to protect the site against climate change and to maintain its globally important conservation values.

Photo credit: GIZ (Shambhavi)

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Photo credit: GIZ (Kruttika)

9 ANNEXES

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

The CAM method and the overall guidance for its application in the adaptation planning and management of Ramsar sites in India are set out in detail in the companion volume to this report – the *Climate Change Vulnerability Assessment and Adaptation Methodology for Ramsar sites in India – A guide for Ramsar site managers.* The guide is accompanied by a series of five PowerPoint presentations that describe the four case studies and the CAM methodology as training and awareness-raising materials.

8.1.1 Impact and vulnerability assessment

The starting point for the CAM method of vulnerability assessment and adaptation planning 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 for the vulnerability assessments and adaptation planning.

The climate change impact and vulnerability assessment follow 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.

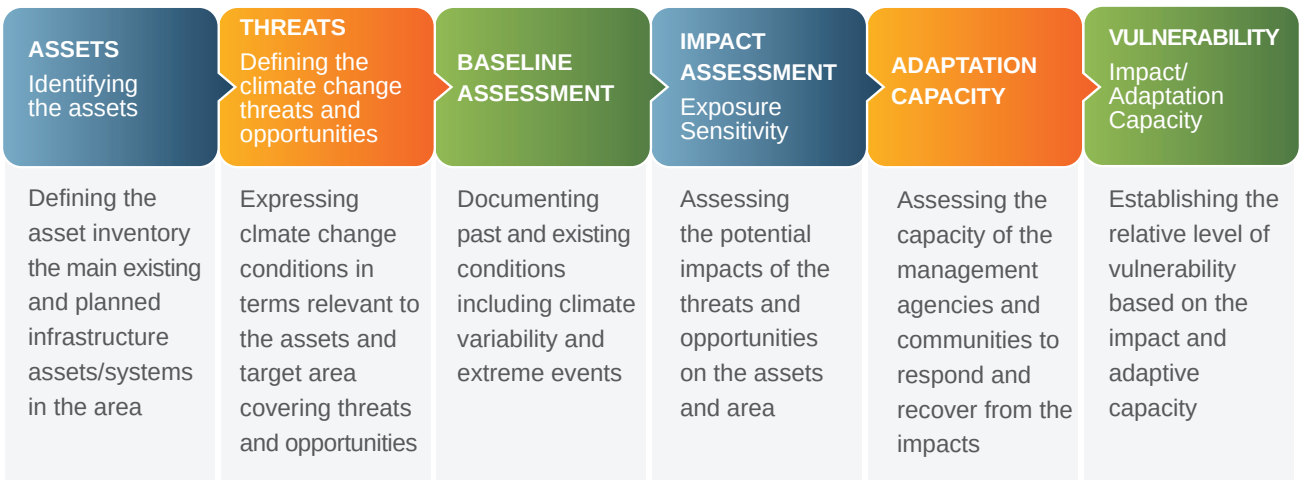

Figure 18 *Climate change impact and vulnerability assessment steps*

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 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 (Figures 19 – 22).

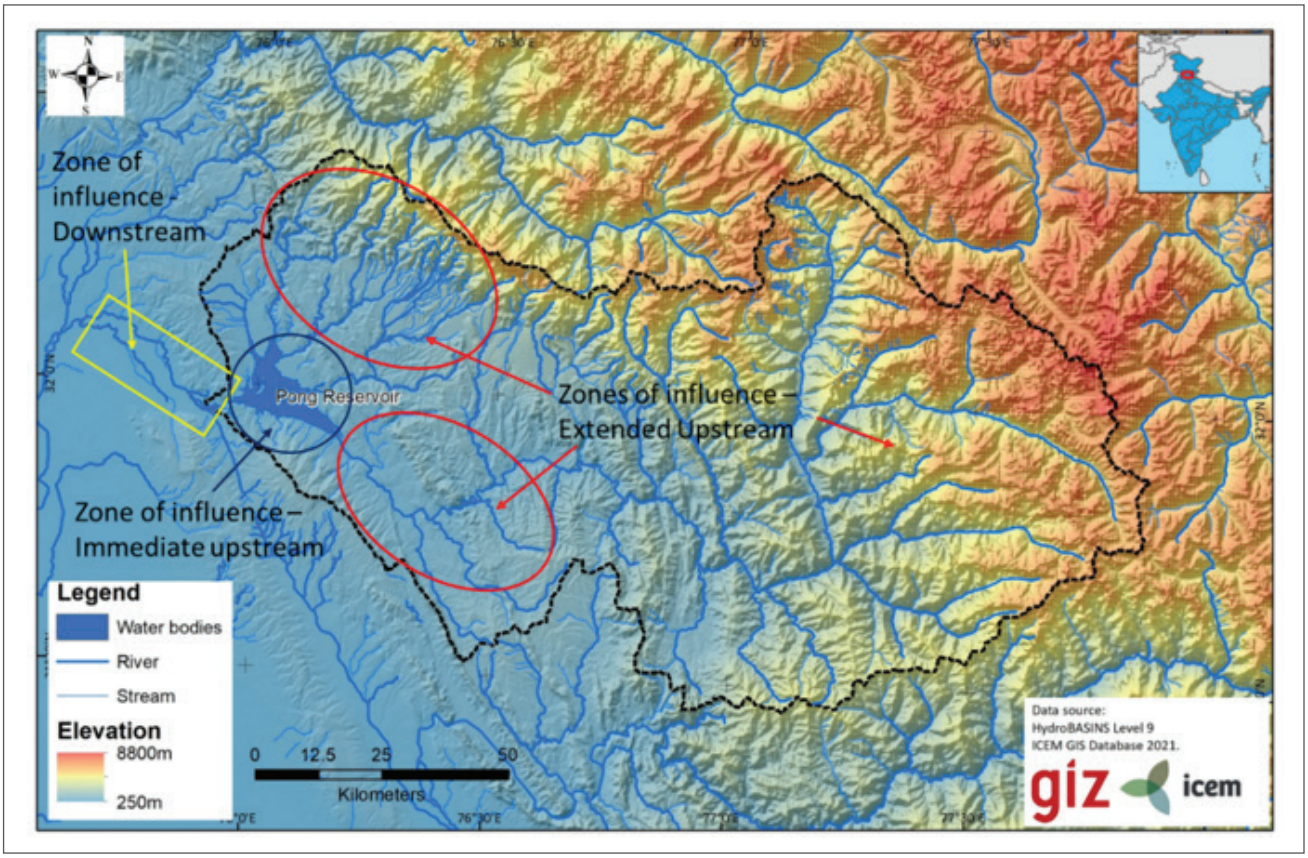

Figure 19 *Pong Dam Reservoir and zones of influence within its catchment*

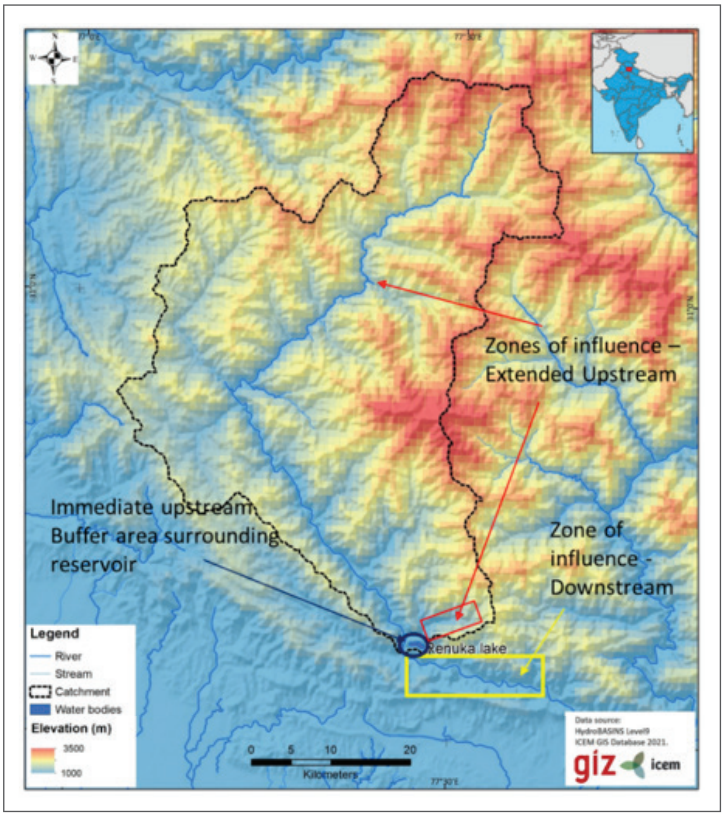

Figure 20 *Renuka lake and zones of influence within its catchment*

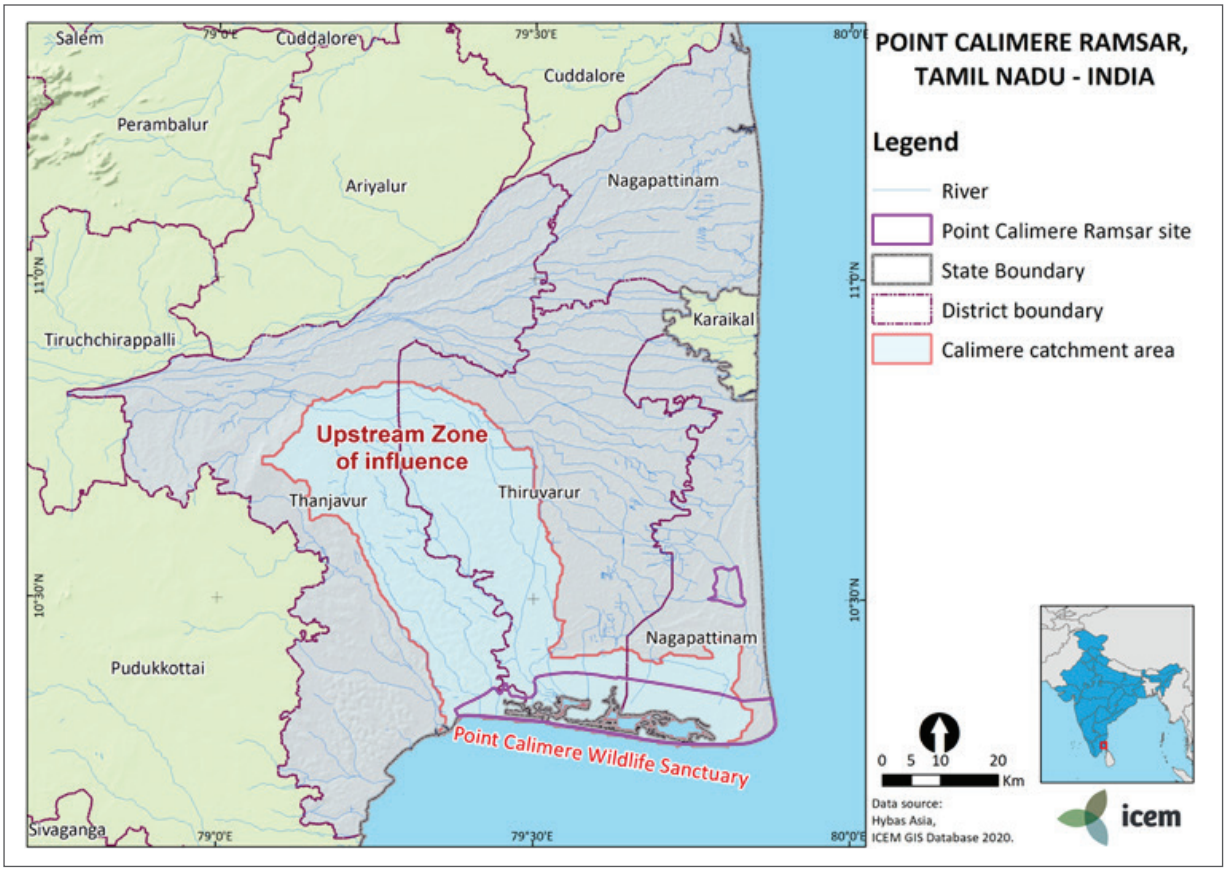

Figure 21 *Point Calimere Ramsar site and its upstream zone of influence*

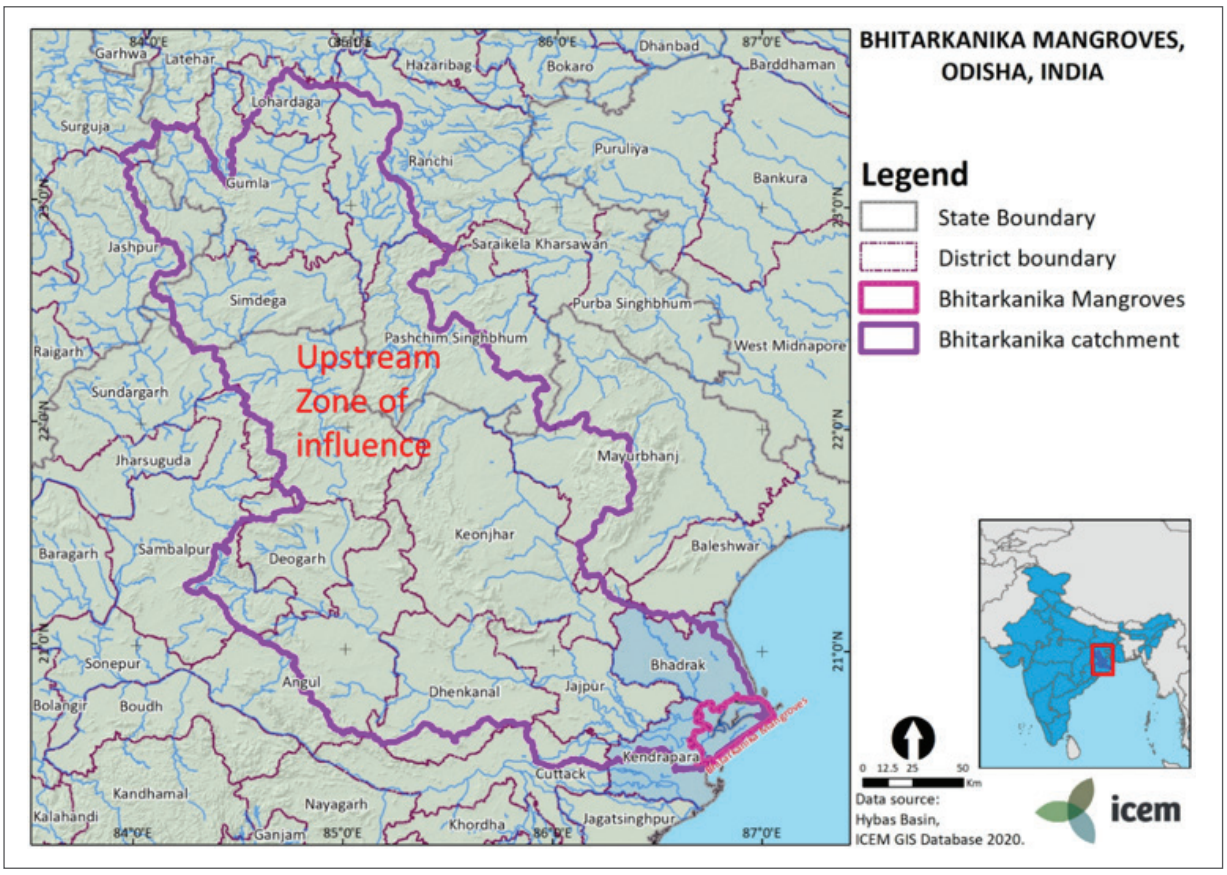

Figure 22 *Bhitarkanika Mangroves site and its upstream zone of influence*

In terms of 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 long enough 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 focus of the assessments 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 multipurpose Pong dam or water control and erosion structures.

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 on all of the natural, ecosystem service and infrastructure assets present in each Ramsar site, because the level of details 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 from the baseline assessment of the wetlands 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 example, a mangrove swamp might function to protect against cyclones and provide livelihoods for local communities. The Renuka Lake wetland provides a wide range of services including cultural and religious functions. Defining the primary 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. When the primary purpose is not clear as is the case in the Renuka site – this creates challenges for its effective conservation and management.

The individual assets fall within the following categories:

- **Physical infrastructures** that determine and protect the wetland character.
- **Key habitats** that define the wetland ecosystem.
- **Keystone species** for those habitats, without which the habitat would change or which are essential for the maintenance of ecological processes
- **Important Wetland species for Ramsar site definition.**
- **Ecosystem services** important for local people using the Ramsar site.

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 its catchment, 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 designation of the Ramsar site.
- **Sensitivity to environmental change:** the asset should be known to be sensitive to change 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 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 19).

Table 19 *Scoring sheet to aid target asset selection*

Criterion	Question
Representativeness	To what extent is the habitat, species or ecosystem service representative of the site?
Ecololgical Significance	To what extent is the habitat, species or ecosystem service significant for ecologica lprocesses?
Ramsar Importance	To what extent is the habita 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 situation, trends and drivers affecting the target system/asset. It involves documenting climate and hydrological change projections which 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):

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

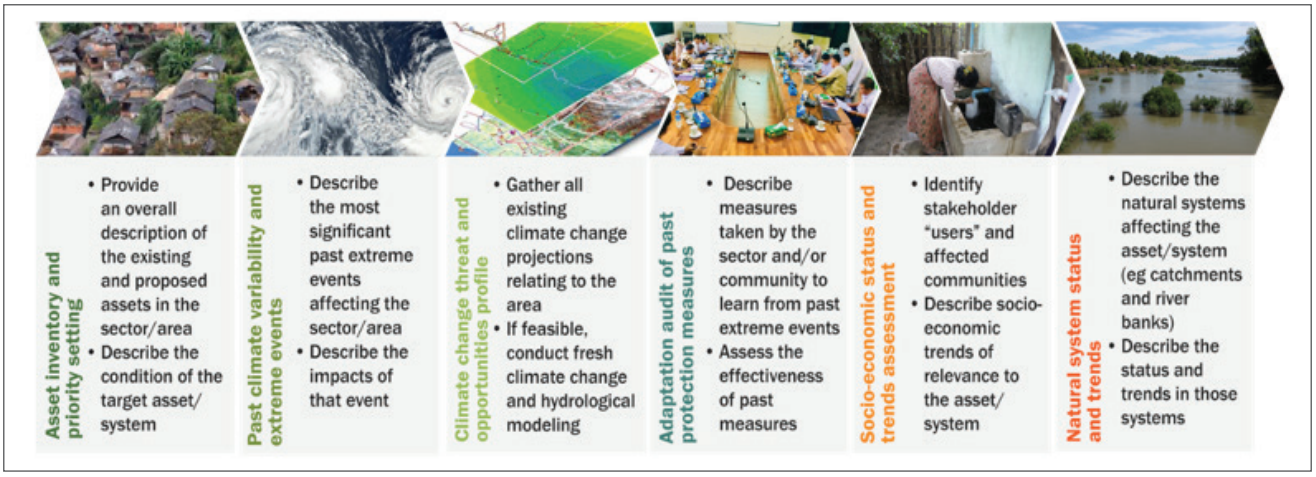

Figure 23 *Components for the baseline assessment*

For this assessment, the description of the past and existing situation and conditions in the four Ramsar sites were derived from existing information, literature, surveys and reports. Main references include:

- Ramsar Site Information sheets, which describe the sites and the criteria used for designation.
- Subsequent surveys and monitoring on flora and fauna in 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 four Ramsar sites.
- The management plans that are available for the Ramsar sites or forest areas around them.

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

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

- Description of key wetland ecosystem functions and habitats;
- A species/systems database including climate tolerances;
- Description of impacts of past extreme events (including results of participatory flood mapping with stakeholders);
- Identification of existing threats and pressures acting on each of the wetlands;
- Ecosystem profiles covering key habitats and ecosystem services; and
- Analysis 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 containing three key elements: (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 was not available. This method was conducted with support from experts and communities in combination with GIS digitising techniques.

9.1.4.1 Past extreme events and trends

Past extreme events that include floods, storms, landslides and drought are important to 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. Geographic area was also an important consideration for examining historical extreme events. It was necessary to assess beyond the primary boundary of each Ramsar site, including upstream and downstream zones of influence (Figures 19 to 22).

9.1.4.2 Climate change and hydrological projections

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

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

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

- Hydrological modelling reports for each of the Ramsar sites[38,39,40,41]
- National assessments in 2020 by the Ministry of Earth Sciences (MoES)[42], and in 2010 by the Indian Network on Climate Change Assessment (INCCA)[43].

- **Hydrological modelling reports**

The hydrological report for Pong Dam Reservoir is a final report, recently developed by a GIZ's 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 RCP4.5 and RCP8.5 scenarios. Ensemble mean of three regional climate models (RCM), namely, REMO (from MPI), RCA4 (from SMHI) and CCAM (from CSIRO) is used for the analysis. The report provides valuable projections of changes in precipitation (in %), and maximum and minimum temperatures (in oC) across the Pong Basin for 2021-2050 and 2071-2100 future periods, 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 oC) for the baseline as well as future projections, that are important to the vulnerability assessment process.

Such detailed assessment has not been available for the other Ramsar sites. Provided hydrological reports for Renuka Lake, 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 climate change assessments in the Ramsar sites were conducted using different approaches. In particular, projections at Pong Dam were based on an ensemble mean of three regional climate models including REMO, RCA4 and CCAM. Whereas projections at Bhitarkanika, as described in the interim hydrological report, were based on the ensemble of other three climate models including HadGEM2, GFDL, and MIROC (conducted by Central Water Commission – CWC in 2015).

[38] 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.
[39] ACWADAM and PSI, 2020. Renuka Wetland Hydrogeological Assessment, Management Strategies and Capacity Building. Interim Report. Prepared for GIZ.
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[41] Chilika Development Authority, 2020. Hydro-ecological assessment for integrated management of Bhitarkanika Ramsar site, Odisha. Interim Report. Prepared for GIZ.
[42] 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.
[43] 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.

- **National assessments**

The most recent national assessment was reported in 2020 by the Ministry of Earth Sciences (MoES) indicating future projections of precipitation, temperature, sea level, and some other parameters across the India region for the near (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 by 2030s, with respect a baseline period 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 details 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 are normally 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 Himalaya will increase 20-40%) that would not be suitable for specific site-based assessment.

- **CEM'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 modellings, datasets, and time durations) should be applied for climate change projections at 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 based on the objective of the study and the subjects chosen. The selection process is also depend 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 characterized 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 to 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).

RCP8.5 (Representative Concentration Pathways) scenario is used in the IPPC Fifth Assessment report (AR5). In RCP8.5, emissions continue to rise throughout the 21st century. This scenario combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to 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 following steps:

Step 1: Initial selection of GCMs

The initial selection was based on the evaluation of climate models that have been used in recent studies in India (i.e., CORDEX-SA models used for Pong Basin and the National assessment in 2020). From the evaluation, 10 common GCMs used in these studies that demonstrated a good performance were selected for further steps. The 10 GCMs included 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 Δ P) were compared against projection results reported in the recent studies where relevant (i.e., projections reported for Pong Basin and in the National assessment in 2020) (Figure 25 and Figure 26). From the comparison process, three GCMs, which 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.

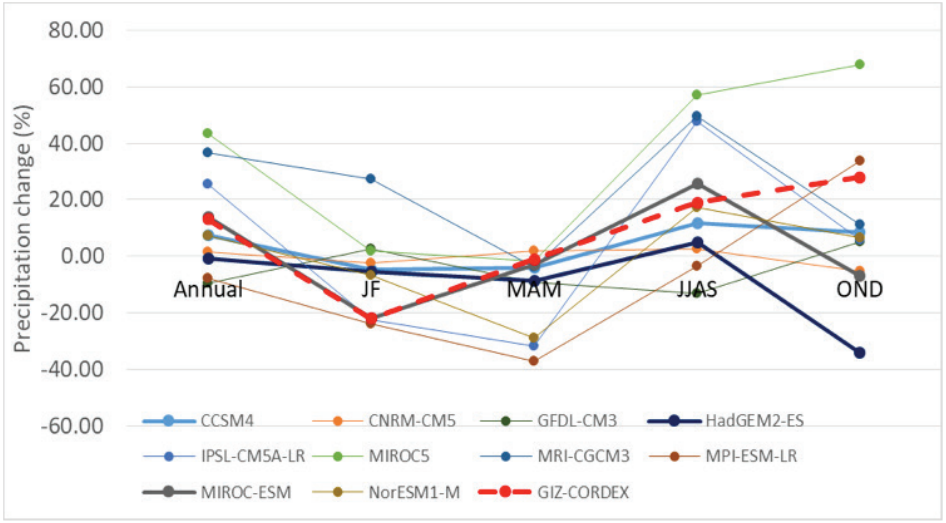

Figure 25 *Changes in precipitation in Pong Basin by 2050s derived from the 10 GCMs in comparison with results reported CORDEX-SA models (GIZ). The three selected GCMs are the thicker lines.*

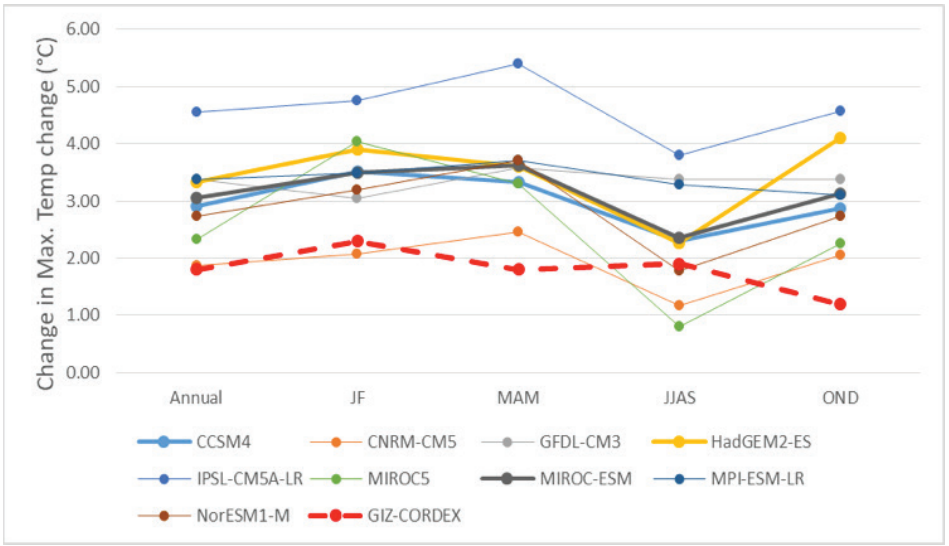

Figure 26 *Changes in temperature in Pong Basin by 2050s derived from the 10 GCMs in comparison with results reported CORDEX-SA models (GIZ). The three selected GCMs are the thicker lines.*

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 CO2 concentrations or to prescribe anthropogenic CO2 emissions and simulate CO2 concentrations. HadGEM2-ES has a high climate sensitivity of approximately 4.6°C for a doubling of CO2 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 were generated with annual and seasonal changes in precipitation and temperature (presented in Section 2.6). 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 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 inputs and social development inputs such as land-use changes, hydraulic constructions, water realocation projects, waste/wastewater disposal. Also, the intensification of agriculture increases sediment loads in drainage corridors and the use of fertilizers which eventually is transported to delta regions through land runoff and river discharge, which are significant in 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 of 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. As important, 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. Assessing 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.

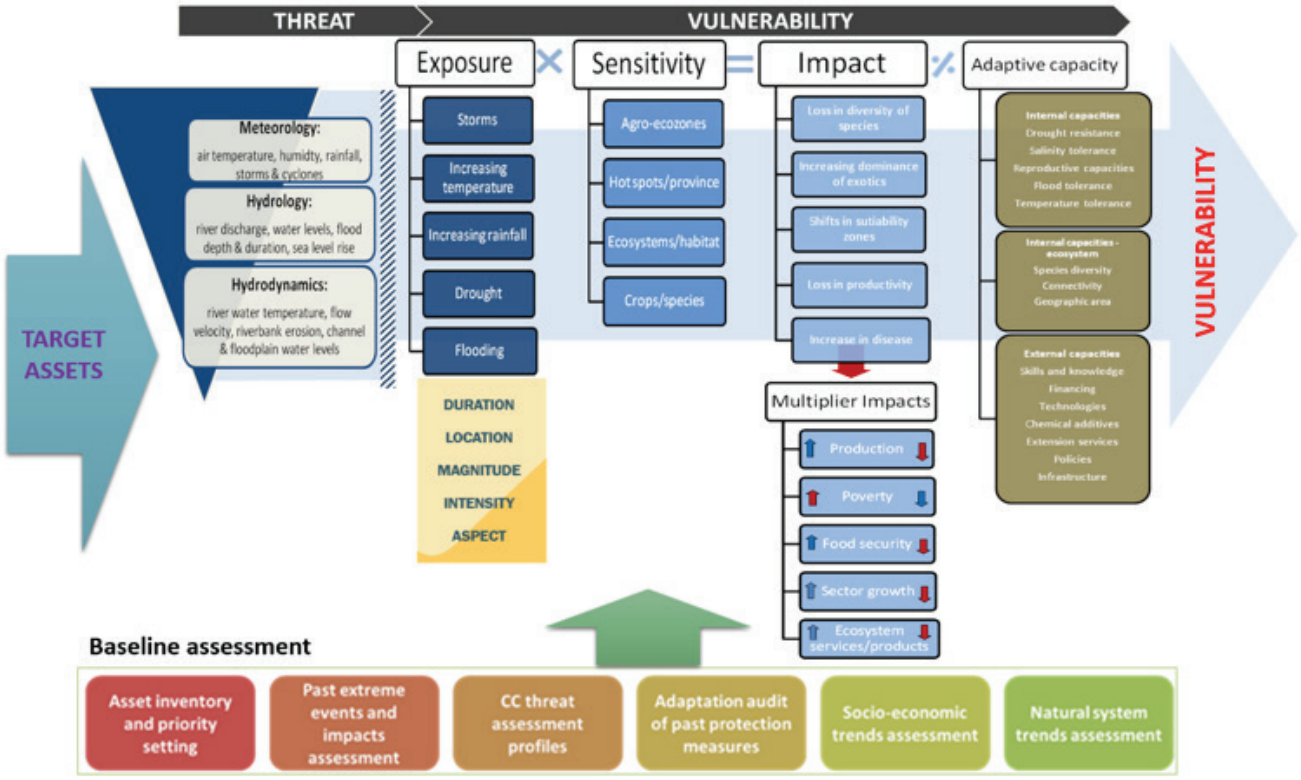

Figure 27 *Illustration of parameters and issues considered in the CAM baseline and vulnerability assessment process*

(I) Exposure

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

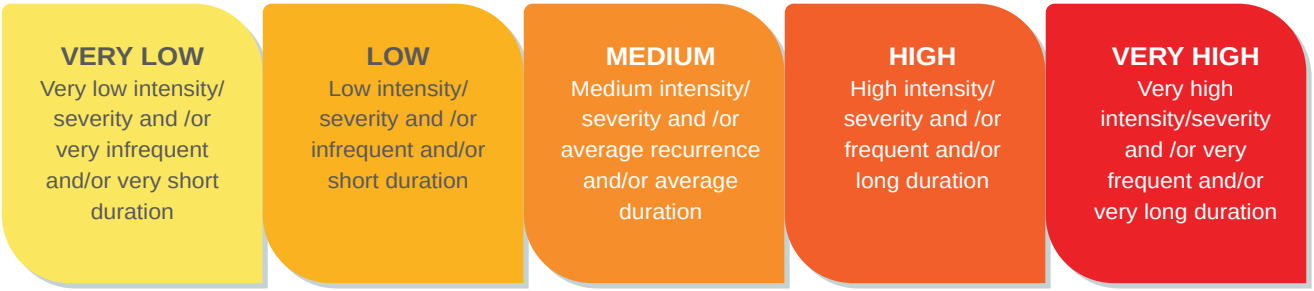

Figure 28 *Exposure scoring protocol*

(II) 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 system sensitivity from 'very low' to 'very high' (Figure 29).

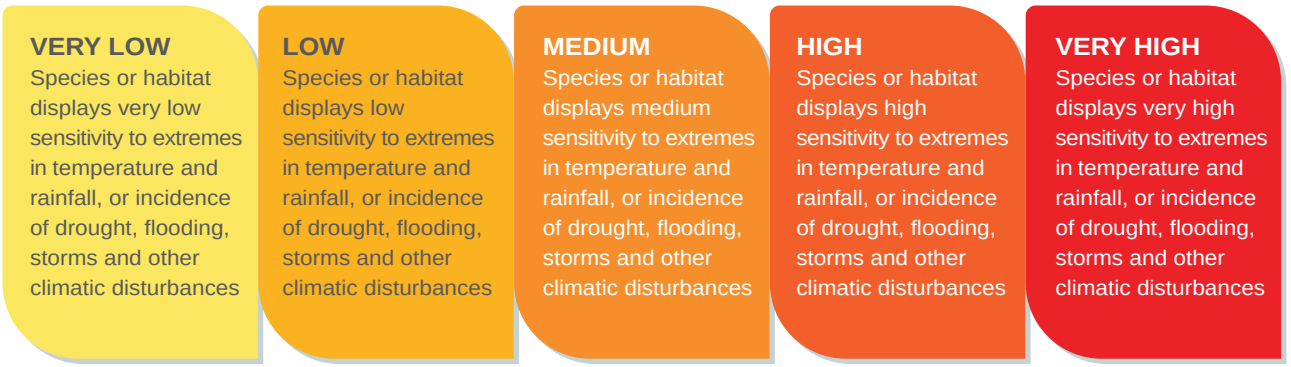

Figure 29 *Sensitivity scoring protocol*

Some of 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 range of temperature or precipitation, or seasonal patterns

Narrow breeding habitat: The species may have a small preferred breeding range available to them, which limits their population and possibility to spread 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 level of existing trends and 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 would be restricted to an area with a deteriorating climate increasingly outside its comfort zone.

Dependent on interspecific relationships: The species or assemblage of species in a habitat are usually dependent on each other, e.g. for food, for refuge, 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 rise, day length, rainfall at the start of monsoon, increased flow in the rivers, especially for breeding or migration. If these are changed they may be more sensitive.

The CAM tools at this stage consist of a Vulnerability Assessment Matrix as illustrated in Table 20. 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 21.

Table 20 *Vulnerability Assessment Matrix for recording and annotating exposure, sensitivity and impact scoring*

Threat Category	Details of threats	Impact Assessment				Adaptive Capacity	Vulnerability (impact x adaptive capacity)
		Exposure	Sensitivity	Impact Level (exposure x 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 21 *Determining impact score from sensitivity and exposure*

		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

The impacts of climate change on each site and its target assets were described in the Vulnerability Assessment Matrix (Table 20). The listed direct and indirect impacts provided the basis for defining the adaptation responses. Some of 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

o **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 for 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) internal capacity of the species,(2) 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.

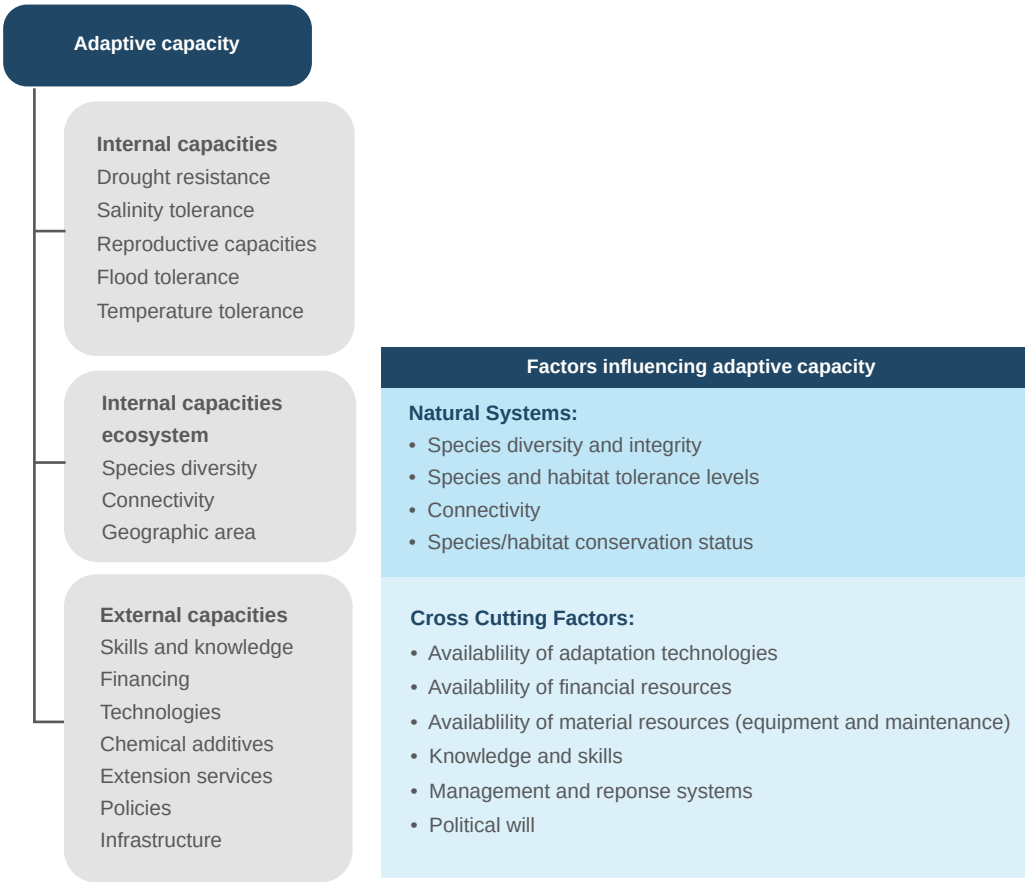

Figure 30 *Adaptive capacities and influencing factors*

Figure 31 *Adaptive capacity scoring for external capacities*

The assessment of the adaptive capacity of the wetlands and their components were drawn from the past science 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 would also be 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 the increasing severity of the 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 22.

Table 22 *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 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

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 which will, in turn, lead to ecological and ecosystem service shifts in both space and time as illustrated in Table 23.

Table 23 *Shifts in climate, ecology and ecosystem services*

Climate shifts	Ecological shifts	Ecological 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 (eg. 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

Climate shifts	Ecological shifts	Ecological shifts
Seasonal shifts (time) • **Onset and end** • **Variability**	Body size changes – warming associated with decreased body size	Reduced availability and access to NTFPs
	Genetic changes (eg tolerance shifts; stress proteins)	Reduced water availability
	Accelerating loss of populations & 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 – eg flash flooding and soil loss in uplands** • **Macro events – eg 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 heatwaves.

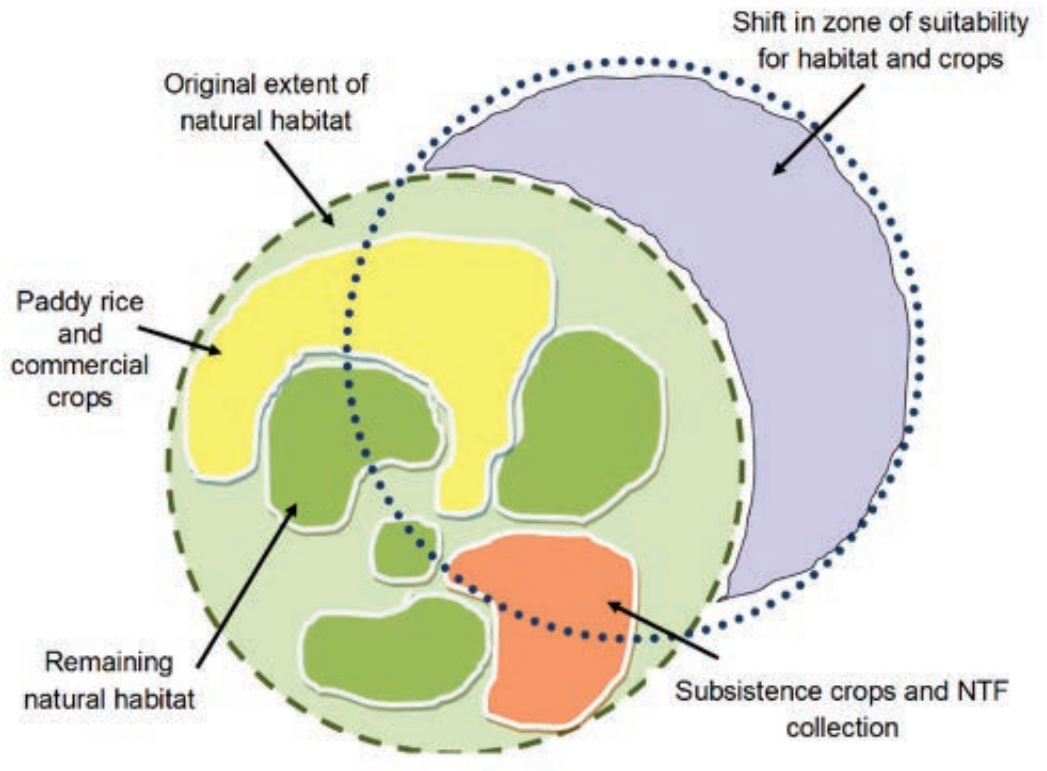

Figure 32 *Illustration of a geographic shift in suitability for habitat*

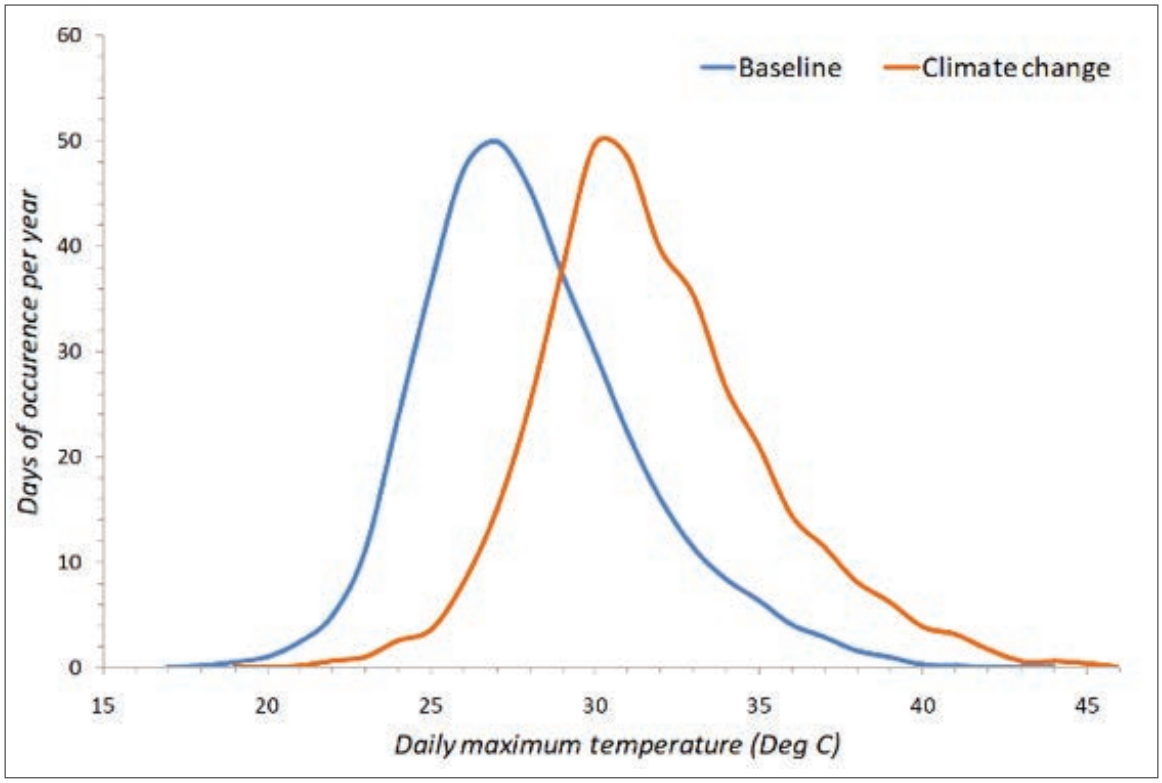

Figure 33 *Temporal shift increasing number of days with increased maximum temperature*

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 34, 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.

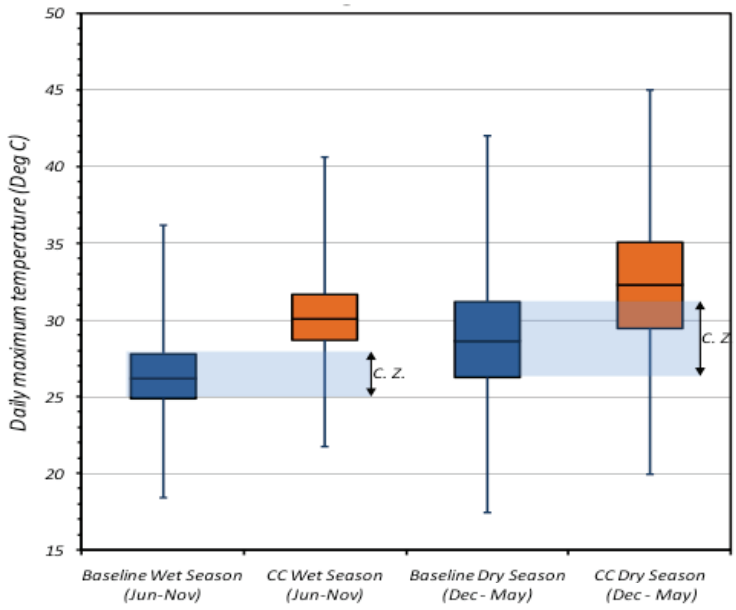

Figure 34 *Illustrating comfort zones: Daily maximum temperatures in the wet and dry seasons*

Each habitat and species have different seasonal comfort zones for temperature and rainfall, and we try to define these for the target assets with references to literature on their natural range, their growing requirements, and breeding cycle requirements for example. There are databases such as the FAO Ecocrop database[44], CABI Forest Science database[45], FishBase[46], the Reptile database[47], the IUCN Red list data[48], and the India Biodiversity database[49] which may be used to source this information for the species or similar surrogate species (if detailed species-specific data is not available).

9.1.7.3 Geographic hot spots

The identification of geographic hotspots or areas which may be highly vulnerable to climate change (e.g. 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 hotspot maps can be developed from increased temperature impacts.

Hotspots may be defined depending on 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 range, degraded and/or under acute pressure, severely restricted geographic range and rare or threatened species. Alternatively, low adaptive capacity hotspots could be defined by mapping poor connectivity, low diversity and tolerances, or homogenous systems.

The climate change projection maps that are 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 hotspots.

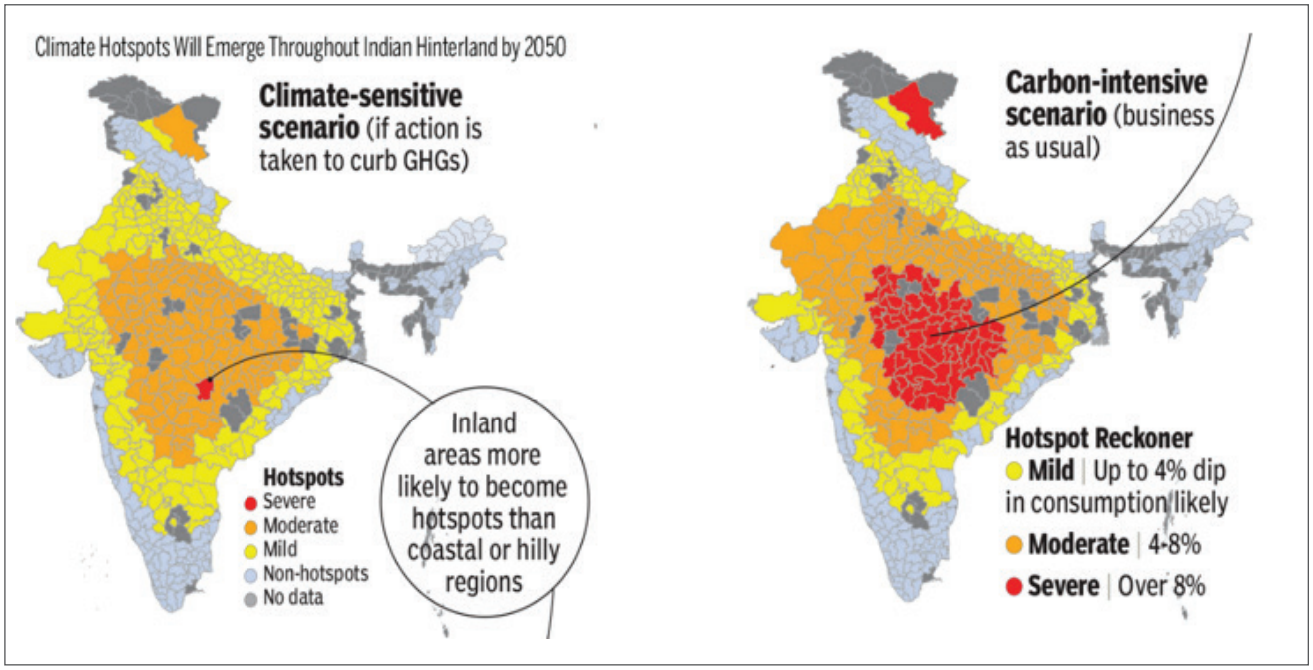

Figure 35 *Examples of India-wide temperature defined hotspots under two climate change scenarios (Source: Mani et al. 2018)*

[44] http://ecocrop.fao.org/ecocrop/srv/en/home
[45] https://www.cabi.org/forestscience/forest-trees/
[46] https://www.fishbase.de/
[47] https://reptile-database.reptarium.cz/
[48] www.iucnredlist.org
[49] https://indiabiodiversity.org/

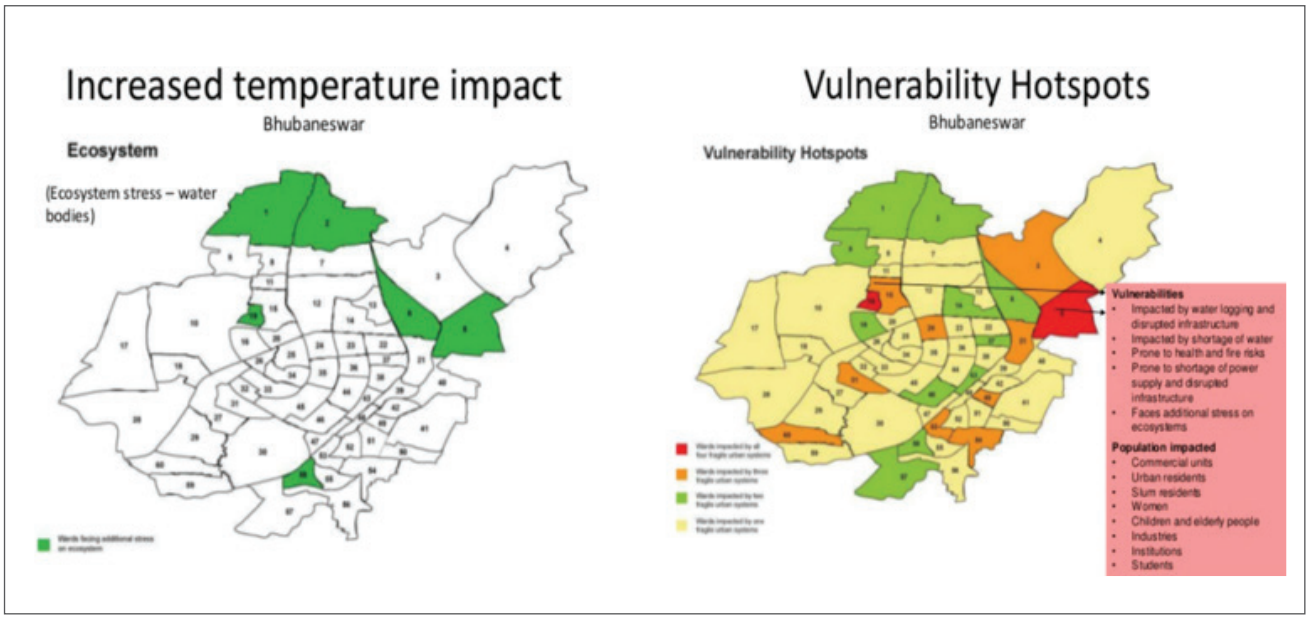

Figure 36 *Example for developing vulnerability hotspots from maps of increased temperature impact (Source: Dr W G Prasanna Khumar, Centre for Climate & Disaster Management, https://www.slideshare.net/wgpkumar/climate-change-and-india)*

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 to note climatic shifts. Ecological zones may have detailed biophysical descriptors of elevation, temperature, rainfall and landform, natural system descriptors with vegetation and soils and agricultural, livestock and fisheries profiles. For instance, Figure 37 shows the zones for soil moisture content in Odisha on a particular date.

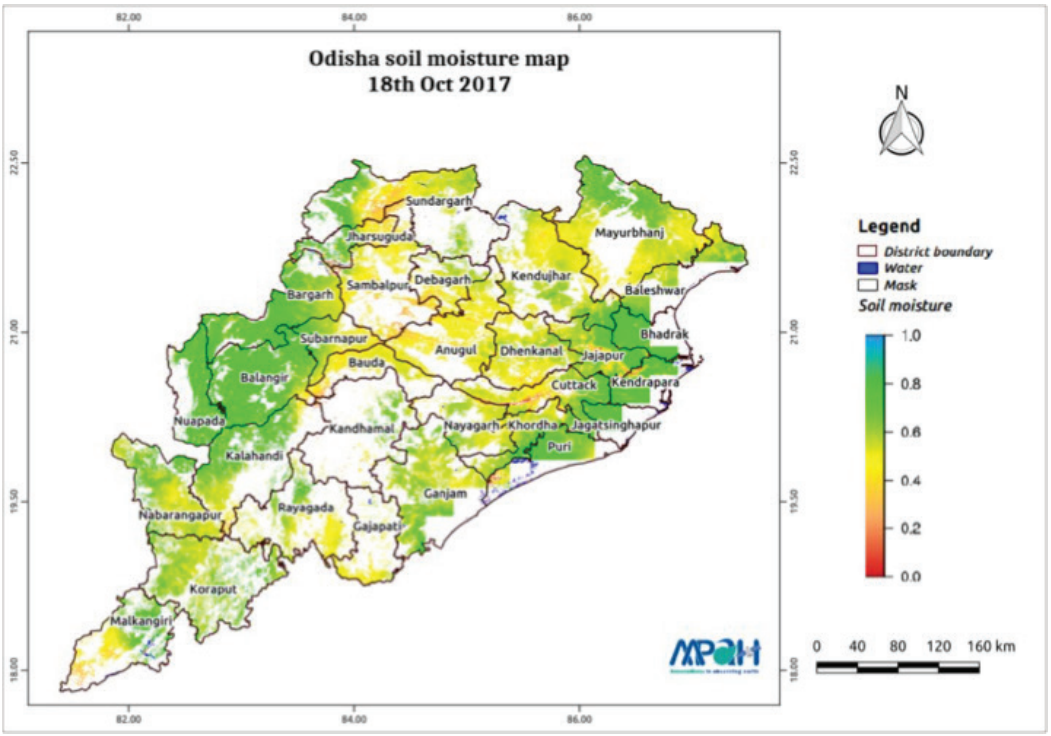

Figure 37 *Odisha soil moisture zonal map*
(Source: Aapah Innovations, http://www.aapahinnovations.com/soil-moisture-map-state-odisha-2/)

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[50] (GDD), reflecting latitudinal and altitudinal temperature gradients; (ii) the aridity index (Trabucco et al., 2008), which forms an expression of plant-available moisture; and (iii) temperature and (iv) potential evapotranspiration seasonality, which express both seasonality and continentality (Metzger, 2013). The two Ramsar sites in Himachal Pradesh have greater variation 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 changes in annual precipitation in the Pong Basin (Figure 38). These variables are used in overlays to assess the potential changes in bioclimatic zones.

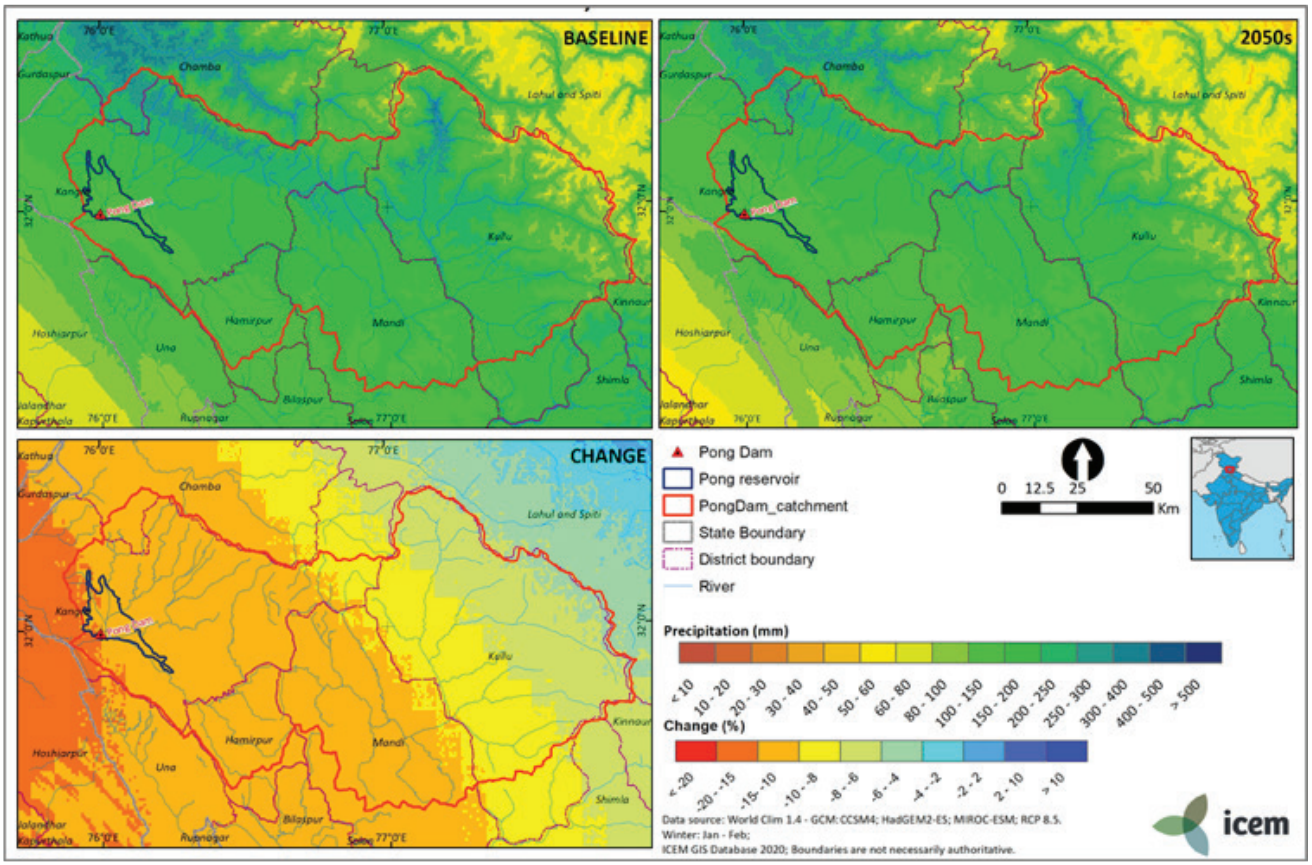

Figure 38 *Climate change zonal map – changes in annual precipitation In Pong Basin.*

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 minimizing 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).

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

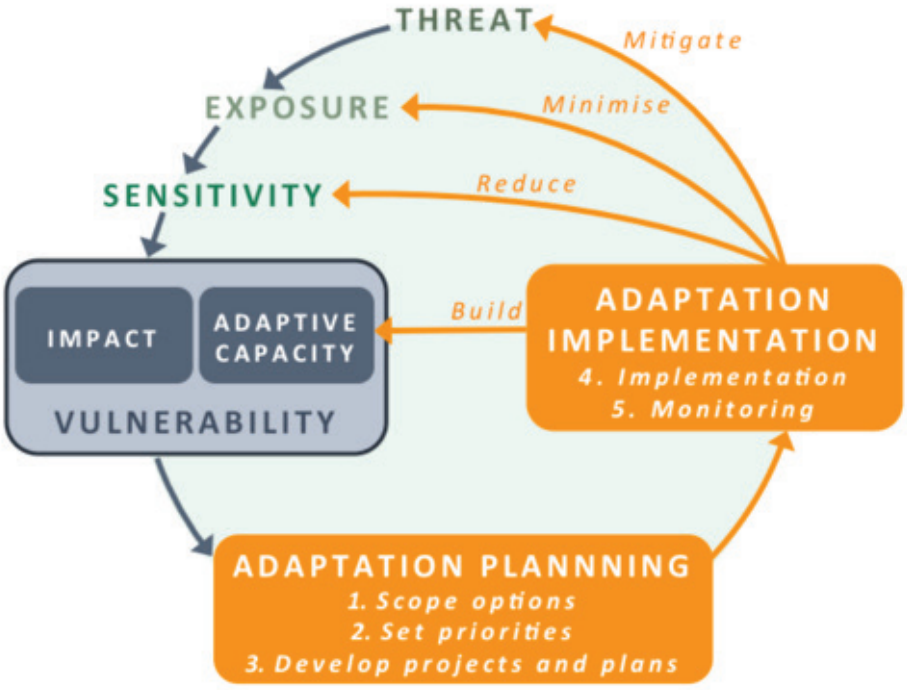

Figure 39 *Schematic of adaptation options to address climate change impacts on an asset*

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;
- distinctive character and tolerance levels of each ecosystem to change;
- different spatial levels of ecosystems which are important to social-ecological system health and productivity (from soil to ecozone);
- services which assemblages of wild species and other natural resources provide to social-ecological systems; and
- 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 24 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 the creation of 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 24 *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 beavers and natural ponds and pools • 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 habitat 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 to move inland
Identify and protect climate refugia	Climate refugia are local areas that have experienced less climate change than 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 technical complexity, the capacity of the implementing agencies and user community, availability of equipment and materials and cost.

The effectiveness of adaptation options is the degree to which each adaptation option would be successful in avoiding or reducing the negative impacts of climate change on the target system and enhancing any benefits and opportunities which 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 25 and prioritised using the adaptation matrix of feasibility and Table 26

Table 25 *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 26 *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 27 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 which 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. The significance step is normally reserved for assessing major infrastructure proposals or assets and is not recommended for use in adaptation planning for Ramsar sites.

Table 27 *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 the H and VH threats (only consider direct impacts)	**Likelihood** The chances of the impact occurring	**Seriousness** of 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 structural 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 flows • Flash floods	1. Further damage to diversion weir	VH[17]	H[21]	VH	1. Rebuild diversion weir taking CC into account	L[25]	VH[28]	H
	2. Unable to raise water levelsto reach intake	H[18]	H[22]	H	2. Improved river bed protection downstream of core wall	M[26]	H[29]	H
	3. Intake becomes blocked with debris	VH[19]	VH[23]	VH	3. Increased mainteinance / unblocking of existing	M[27]	M[30]	H
	4. Sediment enters main	H[20]	M[24]	M				

9.2 ANNEX 2 – LIST OF VULNERABILITY ASSESSMENT MATRICES FOR BHITARKANIKA MANGROVES

The matrices are attached as complemented materials.

Table 28: *Vulnerability Assessment Matrices*

Target asset	Attached file
Catchments	AAS2010-REP-003-02 Final Report Bhitarkanika (Annex 2.1 VA_Catchment).docx
Mangrove habitats	AAS2010-REP-003-02 Final Report Bhitarkanika (Annex 2.2 VA__Mangroves).docx
Saltwater Crocodiles	AAS2010-REP-003-02 Final Report Bhitarkanika (Annex 2.3 VA_Crocodiles).docx
Olive Ridley Turtles	AAS2010-REP-003-02 Final Report Bhitarkanika (Annex 2.4 VA_OliveRidley).docx
Fisheries	AAS2010-REP-003-02 Final Report Bhitarkanika (Annex 2.5 VA_Fisheries).docx
Tourism and recreation	AAS2010-REP-003-02 Final Report Bhitarkanika (Annex 2.6 VA_Tourism).docx

[17] 100 year return period flood increases in size by 50% increasing scouring of khola bed material
[18] Damage to the weir crest by increased flood volumes
[19] Rainfall intensifies increased by 20% causing the catchment area in the Churia mountains being mostly forested area but steep more liable to landslides and debris flow
[20] Average monthly flows increasing during the pre-monsoon period with maximum increase in July will bring more sediment into the main canal
[21] Increasing lilelihood of diversion of 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 – LIST OF VULNERABILITY ASSESSMENT MATRICES FOR BHITARKANIKA MANGROVES

Annex 2.1 - Vulnerability Assessment Matrix for the Catchment

ASSET NAME: CATCHMENT - RIVER BASINS OF BRAHMANI AND BAITARANI INFLUENCING BHITARKANIKA RAMSAR SITE

ASSET DESCRIPTION: Brahmani River Catchment area is one of the major inter-state east-flowing rivers amongst the Peninsular rivers in India. The basin covers Jharkhand, Chhattisgarh and Odisha states and drains an area of 39033 km^2 [1]. A major portion of the Baitarani basin lies in Odisha, except a small portion which lies in Jharkhand, it drains an area of 10,982 km^2. The combined basin consisting of Brahmani and Bitarani extends over an area of 51822 km^2. There are over 42 dams constructed and 9 projects under construction and a few proposed in the catchment area of these two rivers[3].

Salinity has been increasing due to human activities such as (1) Rengali dam and several other dams, which causes less freshwater flowing into the Brahmani river system; (2) Siltation of river mouths due to reduced inflows; (3) Increase in water consumption for irrigation, aquaculture, tourists, and requirement of people in the villages. This is the main cause for significant changes in the density and distribution of plants and key species - mangroves, crocodiles, turtles, and birds. The water drawn from the wetland for aquaculture ponds and the polluted drainage water from the ponds entering the wetland creeks and rivers is a concern. See Annex 2.2.1 for technical details.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Oct)	Increase by 3.9% (i.e., 48.2mm, from 1262.2 to 1310.4 mm) by 2050s. A more significant increase for immediate upstream areas in the catchment (11.2% or 140mm). This increase is likely to be concentrated in more intense events	**High**	**Medium**[4]	**High**	**Direct impacts**[5]**:** • Aquifers will be recharged in the catchment area (+ve) • Siltation in the catchment area will hinder the freshwater inflows into the wetland (-ve) • Erosion of the riverbanks would increase, rivers and creeks would be widened (-ve) • Rengali dam and other water management projects could reduce the inflows and prevent floods (+ve)	**High**[6]	**Medium**

[1] http://www.cwc.gov.in/mero/about-basin
[2] https://indiawris.gov.in/wiki/doku.php?id=brahmani_and_baitarni
[3] https://indiawris.gov.in/wiki/doku.php?id=dams_in_brahmani_and_baitarni_basin
[4] Because of a number of irrigation projects in the catchment area, which will help in storage of water and reduce the impact.
[5] The overall increase in rainfall will have positive as well as negative potential effects on the Ramsar site. The adaptation measures will primarily focussed on reducing the negative effects.
[6] The water will be used for irrigation in the catchment area through the 40+ projects on Brahmani River and Baitarni River basins.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Decrease of rainfall during the dry seasons i.e., Winter (Nov-Jan), Summer (Feb-May	Decrease by 8.2% (i.e., -13.3mm, from 167.0 to 153.7 mm), during the summer by 2050s. Slightly decrease by 5.5% (i.e.,-3.7mm), during the winter.	**High**	**High**[7]	**High**	**Direct impacts:** • Increase in pollution of the surface water and ground-water. The sources of contamination, are domestic sewage, garbage, soil erosion, mining areas runoff and anthropogenic activities with extensive recreational use of the streams and the river. (-ve) **Indirect impacts:** • Landuse changes in the catchment - intense agriculture will draw more water for irrigation especially during drought periods. (-ve) • Industries/agriculture/existence of urban areas will lead to pollution of water. (-ve)	**Medium**[8]	**High**
TEMPERATURE							
Increase of temperature during the Monsoon (Jun-Oct)	Average maximum temperature increase from 31.6 to 33.5oC (increasing by 1.9oC).	**Medium**	**High**[9]	**Medium**	**Direct impacts:** • The increase in temperature would increase low pressure and cause more rainfall in the catchment area. (+ve) **Indirect impacts:** • The sultry climate would lead to an increase in waterborne vectors, might affect the people and life in the basin(-ve)	**Medium**	**Medium**

[7] Increased drawing of groundwater in the catchment area would reduce the water flows for services and into the wetland area.

[8] Because of a number o irrigation projects as well as an increase in rainfall during the rainy season the adaptive capacity is medium.

[9] The higher the temperature would lead to more rainfall in the catchment areas due to low pressure during the monsoon.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase in temperature during Summer (Feb-May)[10]	Average maximum temperature increase from 33.5 to 35.6ºC (increasing by 2.1ºC).	**High**	**High**[11]	**High**	**Direct impacts:** • High surface temperature also increases evapotranspiration, increases demand for irrigation water and other water supply in the catchment • Water pollution will be high during summer (-ve)	**Medium**	**High**
Increase of temperature during Winter (Nov-Jan)	Winter will be warmer with an increase of 2.0ºC by 2050s (from 27.6ºC to 29.6ºC) in average maximum temperature.	**Medium**	**Medium**	**Medium**	**Direct impacts:** • The water bodies in the catchment areas would dry quickly (-ve)	**Low**	**High**
EXTREME EVENTS							
Sea-level rise	Sea level rise projected at 0.5 m by 2040 for the Ramsar site coastline[12].				**Direct impacts:** • In the catchment area, a very little area is exposed to sea-level rise, so there will be the least vulnerability due to sea-level rise.		
Cyclone	Very high risk of increased frequency of cyclones[13].	**High**	**High**	**High**	**Direct impacts:** • There will be floods in the catchment area (-ve) • The aquifers will be recharged increasing water availability (+ve)	**Low**	**High**
Storm surge	Moderate to high risk of up to 5 m storm surge[13].				**Direct impacts:** • In the catchment area, a very little area is exposed to storm surge, so there will be the least vulnerability due to storm surge.		

[10] This is an extreme season with limited rainfall and high temperatures – which tends to place stress on the forests and associated species. It is the flowering season for many plants preparing for propagation during the wet season so it is a sensitive period which would be affected by increasing temperatures.

[11] Water quality will be poor due to pollution.

[12] CWC, 2015. Operational Research to Support Mainstreaming Integrated Flood Management in India under Climate Change Vol. 5b Modelling Report Brahmani-Baitarani.

[13] 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.

Annex 2.1.1 - Technical details of the catchment

Salient Features of Brahmani and Baitarni Basin Extent[14] :

Longitude 83° 55’ to 87° 3’ E, Latitude 20° 28’ to 23° 38’ N
Length of River (Km) - Brahmani (799), Baitarni (355)
Catchment Area (Sq.km.): 51822 (area of Bhitarkanika Ramsar Site 650 Sq.km area).
Average Water Resource Potential (MCM): 28480
Utilizable Surface Water Resource (MCM): 18300
Live Storage Capacity of Completed Projects (MCM): 5070.0
Live Storage Capacity of Projects Under Construction (MCM): 465.0
Total Live storage capacity of Projects (MCM): 5535.0
No. of Hydrological Observation Stations (CWC): 15
No. of Flood Forecasting Stations (CWC): 3

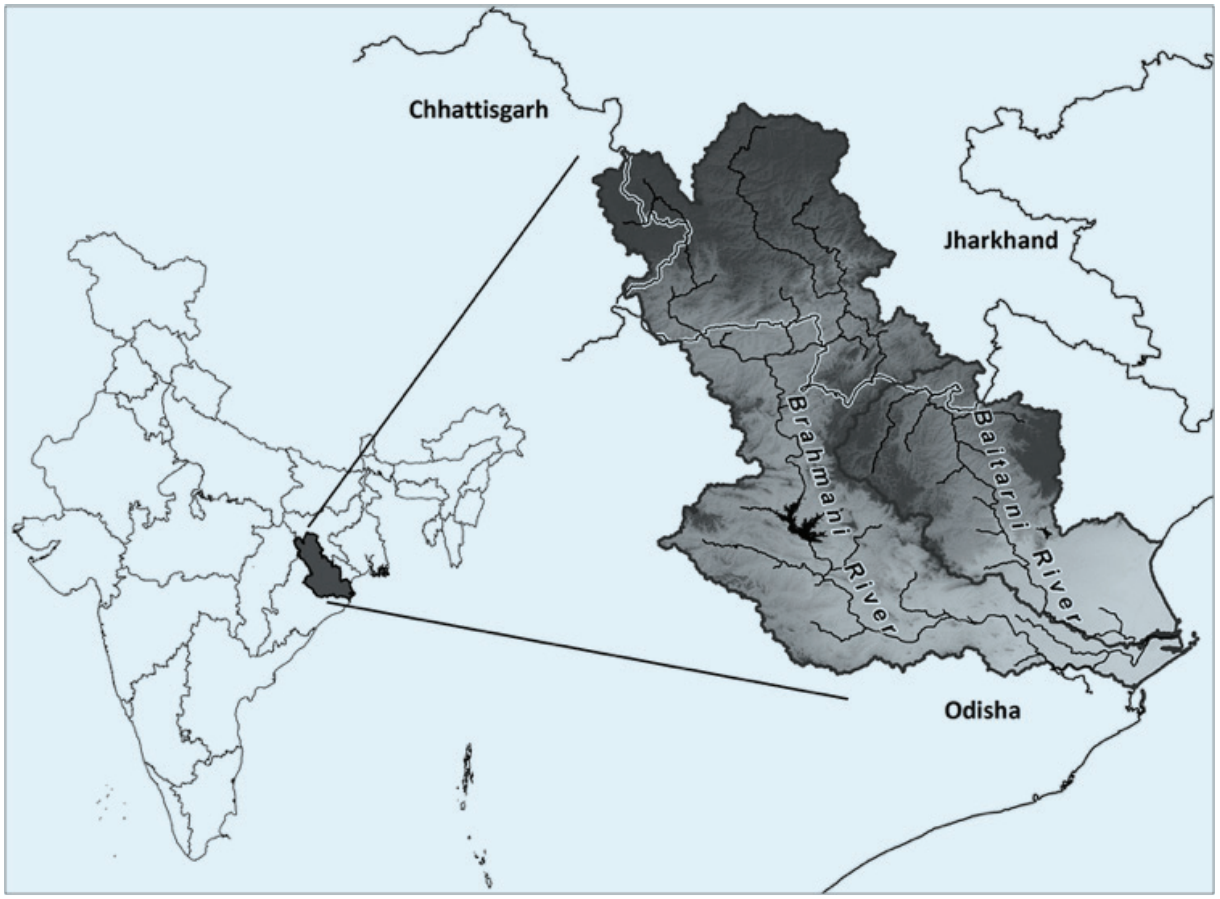

Figure 1 *River Basins of Brahmani and Baitarani*

Annex 2.1.2 – 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 Crocodiles

ASSET NAME: SALTWATER CROCODILES

ASSET DESCRIPTION: Bhitarkanika National Park of Odisha has the largest habitat of the endangered estuarine saltwater crocodiles in India. Brackish wetland and natural lush green mangroves are the peaceful abode of crocodiles in Bhitarkanika. As per crocodile estimation data of Forest and environment department, Rajnagar division, Kendrapada, the population of crocodiles has increased from 1498 in 2008 to 1798 in 2020. The average survival rate of hatchlings is 1% to 1.5%. The life span of saltwater crocodile range 70-100 years.

They are opportunistic feeders that prey on a variety of species like crab, fish, birds, turtles, pigs, small cattle, Buffalo, wild animals. The usual mating period is from January- March. A female crocodile starts the process of nesting in the first week of May. She takes approximately 15 days to set up a safe shelter for her upspring. She digs a small hole of 5 inches in a swampy area in a high place, out of the reach of high tide and create one layer of Hental leaves *(Phoenix Paludosa)* inside the hole and then leys her eggs. A female crocodile lays 50-60 eggs at a time. The eggs are again covered with two-three layers of Hental or Nelia grass and then covered with wet mud, which after drying up create solid protection for eggs. The hatchlings developed from the egg after 60 to 72 days during July month. She tends to stay near the nest throughout incubation. The mother crocodile also creates a 'body pit' of 1 -2 feet deep pit and keep her newborn babies in the pit for a couple of months. Then gradually carry them into the creek. But most of the hatchlings became the prey of predators during their struggle to grow as yearlings. During their egg-laying season, female crocodiles are usually aggressive and can attack humans at even the slightest sign of intruding into their nesting area. So, Forest Department closes the sanctuary from May- July for the protection of tourists as well as crocodiles.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Oct)	Increase by 3.9% (i.e., 48.2mm, from 1262.2 to 1310.4 mm) by 2050s. A more significant increase for immediate upstream areas in the catchment (11.2% or 140mm). This increase is likely to be concentrated in more intense events	**High**[1]	**Low**[2]	**Medium**	**Direct impacts:** • In case of flood due to high rainfall, the basking and nesting area for crocodiles will be inundated by the rising water level of rivers /creeks for a short time (-ve) • Food (fish) availability will increase by the increase in water level. (+ve) • In case of flooding erosion of mudflat lead to a reduction of basking areas. (-ve)	**Very High**[3]	**Medium**

[1] Kendrapada district has affected by flood 11 times in last 20 years (District Disaster management Plan, Kendrapada) mapped under high flood zone area by OSDMA in state disaster management plan. Duration of flood is short. Since Bhitarkanika is closed to sea, the flood water recede very fast with the tidal wave movement.

[2] As the waterlogging period is short, being an aquatic creature crocodile is adoptive to the situation (high tide and flooding).

[3] Crocodile is sensitive to climate change and so sets up the nest in high land. If one side mud flat of the river/creek is eroded, it will use the other side of river for basking. The Ramsar management plan has to develop mounds in mangrove forest for safe salter of animals.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
					• The mortality of newborn hatchlings would increase by getting into floodwater. (-ve) • Increased in pollution in crocodile habitat i.e., river/ Kola creek. (-ve) **Indirect impacts:** • Crocodiles will enter into human habitation and increase crocodile attacks on human and -domestic cattle(-ve)		
Decrease of rainfall during the dry seasons i.e., Winter (Nov-Jan), Summer (Feb-May)	Decrease by 8.2% (i.e., -13.3mm, from 167.0 to 153.7 mm), during the summer by 2050s. Slightly decrease by 5.5% (i.e., -3.7mm), during the winter.	**Medium**	**Medium**[4]	**Medium**	**Direct impacts:** • Potential drying of some sections of the creeks will shrink Habitat(-ve) • Decrease of food(fish) availability (-ve) **Indirect impacts:** • Low growth of juveniles because of lower food availability. (-ve)	**Medium**	**Medium**
TEMPERATURE							
Increase of temperature during the Monsoon (Jun-Oct)	Average maximum temperature increase from 31.6 to 33.5ºC (increasing by 1.9ºC).	**Medium**[5]	**High**[6]	**High**	**Direct impacts:** • Adult crocodiles have a preferred body temperature of around 30-33 oC.(+ve)[7] • Sift the balance between male and female crocodile gender during incubation(-ve) • More hatchling of male crocodiles if the temperature increase is sustained during incubation period 33 oC[8].	**High**[9]	**Medium**

[4] Decrease of rainfall during winter have medium effect on food and habitat, so sensitivity is medium.
[5] As the temperature continues with rain it will have medium exposure for crocodile.
[6] Egg hatching process is highly sensitive to increased temperature during monsoon.
[7] www.iucncsg.org
[8] Eggs at 30 C produce 100% female and at 33 C produce 100% male and temperature in between produce varying sex ratio. The Mechanism of Temperature Dependent Sex determination in Crocodilians, by Danis C Deeming, University of Manchestar.
[9] Under natural conditions, during the incubation period, the crocodiles would have low capacity to adapt to increased temperature. This is an example of where management interventions have increased adaptation capacity. Artificial hatching in regulated temperature is undertaken by Forest department hatching centre (for normal hatching only).

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
					Indirect impacts: • If artificial incubation management is not continued, then gender imbalance would affect the population of crocodiles in long run. (-ve)		
Increase in temperature during Summer (Feb-May)[10]	Average maximum temperature increase from 33.5 to 35.6ºC (increasing by 2.1ºC).	**Very High**[11]	**High**[12]	**Very High**	**Direct impacts:** • Young saltwater crocodiles will take shorter dives in the water and remain in the land for a longer period which will increase the risk of being attacked by predators[13] (-ve). • The mortality of young crocodiles (Yearlings/Juveniles) will be high as they become prey to other predators because of increased time out of water. (-ve) • Reduced food intake is out of water. (-ve) • Shrinking of crocodile habitat some creak lets of Kola creak get dried up. (-ve) • Crocodiles will migrate to a cooler place, out of the sanctuary area.[14](-ve) **Indirect impacts:** • Reduced crocodile population • Potential for increase in crocodile conflict	**Medium**[15]	**Very High**
Increase of temperature during Winter (Nov-Jan)	Winter will be warmer with an increase of 2.0ºC by 2050s (from 27.6ºC to 29.6ºC) in average maximum temperature.	**Very Low**[16]	**Very Low**	**Very Low**	**Direct impacts:** • The increased temperature during winter is good for the health of crocodiles and mating also (+ve)	**High**	**Very Low**

[10] This is an extreme season with limited rainfall and high temperatures – which tends to place stress on the forests and associated species. It is the flowering season for many plants preparing for propagation during the wet season so it is a sensitive period which would be affected by increasing temperatures.

[11] Saltwater crocodile will be directly exposed to increased temperature.

[12] More than 33 oC temperature will be detrimental to growth of young crocodiles.

[13] Acute increase in water temperature result in shorter drive duration(www.ncbi.nlm.nih.gov)

[14] As waters warm as climate change accelerates, crocodiles would be forced to migrate to cooler place face extinction (www.takepart.com>article).

[15] Crocodiles regulate their body temperature by behavioral and physiological mechanism. (Behavioral and physiological thermoregulation of crocodile, report by E.Norbert smith, http://academic.oup.com). The habitat of crocodile is covered by mangroves, so crocodiles maintain balance the body temperature by taking shelter in mangrove shade.

[16] The exposure will be very low, as 2.3 oC increase in winter would not have much impact on crocodile.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Sea level rise	Sea level rise projected at 0.5 m by 2040 for the Ramsar site coastline[17].	Very High[18]	High[19]	Very High	**Direct impacts:** • Submerge of basking and nesting area by submerge of part of mangrove area. (-ve) • Mudflat area will be reduced – reducing basking and nesting habitats of crocodiles. (-ve) • Freshwater fish food will reduce. (-ve) **Indirect impacts:** • Increase in sea fish food availability for crocodiles. (+ve)	Low	Very High
Cyclone	Very high risk of increased frequency of cyclones[20].	Very High[21]	Medium[22]	High	**Direct impacts:** • There will be very Low damage risk for crocodile nests as nests are protected by mangroves branches and covered with mud on the ground. (-ve)	High	Medium
Storm Surge	Moderate to high risk of up to 5 m storm surge[20].	High[23]	Very High[24]	Very High	**Direct impacts:** • Crocodile nest/egg will wash out (-ve) • Juveniles will get out of the sanctuary area to wider catchment area/sea/human habitation due to extensive flooding for a temporary period. (-ve) • Decrease freshwater fish food availability in post surge period. Freshwater flooding from rain or saline storm surge may trap fish in an inappropriate salinity. If this happens rapidly and species that are intolerant to change in salinity may die. (-ve).	Very Low[25]	Very High

[17] CWC, 2015. Operational Research to Support Mainstreaming Integrated Flood Management in India under Climate Change Vol. 5b Modelling Report Brahmani-Baitarani.

[18] Sea erosion has already taken place in Ramsar site and it is increasing. Seven villages of Satabhaya Gram Panchayat has already sub merged in sea.

[19] Saltwater crocodile has resistance to live in saline water but submerge of mudflat and mangrove will pose a big threat for nesting and hatching process which will have negative impact on the population of crocodile.

[20] 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.

[21] Cyclones of high and medium intensity is frequently occurring in Kendrapada district. In last 20 years 4 high intensity cyclones has affected Kendrapada district (District disaster management Plan, Kendrapada 2019). Kendrapada district is mapped under Very high damage zone in State Disaster management Plan.

[22] Occurrence of Summer cyclones are new to this area hence crocodiles are still trying to build their resilience. Though May month is the nesting time for crocodiles which is susceptible to cyclone, but the design of the nest in ground has low risk of damage in cyclone. Nest are raised under Hental (Phoenix Paludosa) which are very high wind resistant plant, so the nest gets good protection during cyclone. Tropical cyclones have negetive short term impact on crocodile nesting (www.tandfonline.com).

[23] The intensity of storm surge is very high, but frequency is medium, so exposure is high.

[24] Bhitarkanika Sanctuary is situated on the sea coast, so sensitivity to Storm surge is very high.

[25] Early warning system can protect the human life, but community is not well prepared to protect the damage to the livelihood asset and infrastructures.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					• Marine Pollution spread to crocodile habitat through storm surge. (-ve) **Indirect impacts:** • Reduced crocodile population. (-ve). • Potential increase in human crocodile conflict. (-ve). • As water bodies will be inundated with saline water, wild animals will go away from creeks in search of freshwater, which will reduce the food basket of crocodiles. (-ve).		

Photo credit: GIZ (Shambhavi)

Annex 2.2.1 – 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 2.3 - Vulnerability Assessment Matrix for the Mangrove habitat

ASSET NAME: MANGROVE HABITAT

ASSET DESCRIPTION: 29 true mangrove species and 72 mangrove associates from different mangrove forest sites of the Bhitarkanika National Park. The classified true mangroves have adaptation mechanisms to resist the physiologically dry surrounding environment and they generally form pure stands in Bhitarkanika National Park. The Forest Survey of India-2013 report highlighted a drop in mangrove cover in the State by nine square km over 2011-from 222 km^2 to 213 km^2. In Kendrapara district alone, where most of Bhitarkanika is located, the drop was by 4 km^2. Since 2014 Forest Dept. has been planting, so the extent of mangrove cover is increasing, but density is reducing. The baseline shows a trend in salinity increasing at all stations. The changes in freshwater flows from the catchment needs to be clarified.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Oct)	Increase by 3.9% (i.e., 48.2mm, from 1262.2 to 1310.4 mm) by 2050s. A more significant increase for immediate upstream areas in the catchment (11.2% or 140mm). This increase is likely to be concentrated in more intense events	**High[1]**	**Medium[2]**	**High**	**Direct impacts[3]:** • The increased rainfall in mangrove areas will have a beneficial impact on growth and health, but this may be limited as the rainfall will be more intense. • With increased rainfall in catchment, flows down the Brahmini and Baitani rivers will increase in monsoon, this will tend to lead to decreased salinity in creeks, with an increase in growth and maintenance of existing species mix. • Wetlands serve as a deterrent to the occurrence of floods. (+ve) • It is also associated with higher runoff, and silt deposition resulting in an accretion of land and associated mangrove migration to newly-built land. (+ve) • There will be submergence in the mangrove habitat. (-ve) • This may be affected by increasing demand for irrigation and domestic water, which will reverse the benefits.	**High[4]**	**Medium**

[1] Mangroves are exposed to direct rainfall and to freshwaters flowing in from the catchment.

[2] Mangrove growth and health are positively correlated with rainfall and the maintenance of appropriate salinity balance. Growth and health also depend on salinity of surrounding waters. Different mangrove species have different tolerance to salinity changes.

[3] The overall increase in rainfall will have positive as well as negative potential effects on the Ramsar site. The adaptation measures will be primarily focussed on reducing the negative effects.

[4] Mangroves will respond/adapt positively to increased monsoon rains. But the total flow of waters in the site will depend on upstream regulation and the release regime depends on competing demands in the catchment. The potential for beneficial regulation leads to a high adaptive capacity.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
					• May lead to increase run-off and levels of pollution (including toxic from industry and pesticides) in creeks. Increased flushing may reduce this threat to some extent. • Increasing sedimentation load could block some creeks and aggravate salinity distribution. **Indirect impacts:** • Increase pollution load may translocate in the food chain affecting certain species and their biology (eg fertility) • An increase in forest cover because of lower salinity and potential expansion of mud flats from higher sedimen load entering the area. • Erosion and waterlogging will increase, very few highlands would be left for wildlife such as deer, wild boars, reptiles, etc. (-ve) • The survival of more saline sensitive species will be enhanced. • The maintenance of a healthy mangrove system will lead to a potential increase in NTFP and livelihoods based on mangroves – honey, mats etc. • Alternatively, the additional extreme rainfall events may lead to dying off of sensitive species (eg shrimps, crabs, frogs, fish and crustaceans) due to toxic flushes of pollutants from sediments in catchment creeks + dilution effect of freshwaters • Spatial distribution of pollutants to be mapped		

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Decrease of rainfall during the dry seasons i.e., Winter (Nov-Jan), Summer (Feb-May)	Decrease by 8.2% (i.e., -13.3mm, from 167.0 to 153.7 mm), during the summer by 2050s. Slightly decrease by 5.5% (i.e., -3.7mm), during the winter.	Very High[5]	High[6]	Very High	**Direct impacts:** • Mangroves are increasingly stressed during the dry seasons by increasing salinity in creeks. Growth and health during this season will be reduced • The denudation or saline blank formations have been noticed in Bhitarkanika forest blocks, which is measured at 1700 acre. It said that the denuded patches, spotted in Mathadia, could be over 30 acres in this block area. (-ve) • Poor rainfall can affect mangrove productivity, growth, and survival by increasing salinity levels. (-ve) • Freshwater flows from the catchment will be reduced further increasing salinity and reducing water quality[7]. **Indirect impacts:** • Long-term stunting and die-back of mangroves • Drying up of wetlands and reduced water holding capacity of the wetlands leads to drought. (-ve) • Shallow water bodies and wetlands are connected hydraulically to the surrounding unconfined aquifer systems. (-ve) • Loss of productivity of mangrove habitat leads to reduced food availability for Fisheries and Crocodiles as top of the food chain • Forest cover and species mix likely to shift – species with lower salt tolerance will be lost[8] • Degradation of mangrove forest can release carbon stored in biomass and wetland soils[9]	Medium[10]	Very High

[5] Mangroves will be directly exposed to the decreased rainfall, and reduced freshwater flows during dry season. Impact will depend upon the duration of the threat and periodicity during time.

[6] Mangroves are very sensitive to increased aridity, and salinity levels. Some mangrove species are more sensitive than others. Baseline is showing decrease in area of dense mangroves.

[7] Dept of Water says no flow changes from the catchment, especially Khola canal which is seen as lifeline for freshwater flows to the Park, 80% comes from Khola canal.

[8] Most mangrove species have a salinity resistance that ranges from 5 ppt to 35 ppt. Only Avicennia marina species can tolerate up to 70 ppt salinity.

[9] The trend for mangrove forest is increasing, but quality and density needs to be assessed.

[10] Mangroves have a natural adaptive capacity to the dry season aridity and salinity by reducing growth and increasing salt excretion, shedding leaves etc. But the upstream management of water flows down river is constrained by other demands reducing adaptive capacity.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase of temperature during the Monsoon (Jun-Oct)	Average maximum temperature increase from 31.6 to 33.5ºC (increasing by 1.9ºC).	High	Medium	High	**Direct impacts:** • The mangroves will be less productive due to the increase in temperature	Medium	High
Increase in temperature during Summer (Feb-May)[11]	Winter will be warmer with an increase of 2.0oC by 2050s (from 27.6oC to 29.6oC) in average maximum temperature.	Medium	Medium	Medium	**Direct impacts:** • The increase in temperature as projected in Brahmani and Baitarani Basin can disrupt physiological processes including a reduction in photosynthetic rates that decrease leaf formation, which affect the net productivity. • The increase in temperature creates shifts in species composition that in turn, can affect the overall metabolism and productivity of mangroves in wetlands. This would impact the migratory birds and turtles. (-ve) • Prolonged dry periods could selectively eliminate aquatic plants (mangroves) that require wetter conditions. (-ve)	Medium	Medium
EXTREME EVENTS							
Sea level rise	Sea level rise projected at 0.5 m by 2040 for the Ramsar site coastline[12].	Very High	Very High	Very High	**Direct impacts:** • Over reduction in Ramsar site area • Mangroves along the northern coastal section of the site, and along the central coastal strip will be lost amounting to approximately 20% of the forests[13]. • Also, fringing mangroves along creeks will be lost	Low	Very High

[11] This is an extreme season with limited rainfall and high temperatures – which tends to place stress on the forests and associated species. It is the flowering season for many plants preparing for propagation during the wet season so it is a sensitive period which would be affected by increasing temperatures.

[12] CWC, 2015. Operational Research to Support Mainstreaming Integrated Flood Management in India under Climate Change Vol. 5b Modelling Report Brahmani-Baitarani.

[13] The natural adaptation response of mangroves to sea-level rise is to move inland – but in this case, there is little area for potential mangrove colonisation. On the other hand, mangroves accumulate sediments from the river and ocean currents and can raise the land level.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					• Loss of frontal mangrove would lead to loss of olive ridley turtle nesting beaches • Anthropogenic pressure would be reduced on the Ramsar site as some of the villages will not exist due to submergence (+ve) **Indirect impacts:** • Reduce NTFP potential and associated livelihood benefits • Reduced habitat for crocodiles and other mangrove fauna • Reduced attractiveness of the area for tourism • Reduced conservation values for some endangered species		
Cyclone	Very high risk of increased frequency of cyclones[14].	**Very High**	**Very High**	**Very High**	**Direct impacts:** • Already cyclones have seriously damaged the mangroves - and systems under stress tend not to recover. The anticipated increase in cyclone occurrence and severity will lead to forest losses (-ve) **Indirect impacts:** • Damage to mangroves will impact the water holding capacity of the wetland (-ve)	**Low**	**Very High**
Storm Surge	Moderate to high risk of up to 5 m storm surge[14].	**High**	**High**	**High**	**Direct impacts:** • Fringing mangroves along creeks will be lost (-ve) • Mudflat area will be reduced - reducing crocodile habitats (-ve)	**Low**	**High**

[14] 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.

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*

Annex 2.4 - Vulnerability Assessment Matrix for Olive Ridley Sea Turtles

ASSET NAME: OLIVE RIDLEY SEA TURTLES

ASSET DESCRIPTION: Olive Ridley sea turtles form enormous congregations along the Odisha coast during the breeding season (November to April) with nesting taking place along suitable nesting beaches at Gahirmatha, Rushikulya and Devi rookeries. Gahirmatha is known to be the largest Olive Ridley's rookery in the World (Bustard, 1976; Dash & Kar, 1990). Incubation takes about 60 days, but since the temperature of the sand governs the speed at which the embryos develop, the hatching period can cover a broad range. Essentially, the hotter the sand surrounding the nest, the faster the embryos will develop. Cooler sand has a tendency to produce more males, with warmer sand producing a higher ratio of females[1]. The hatching occurs between the month of March and April in Gahirmatha sandy beach of Odisha. Estimates of annual turtle nesting in Gahirmatha have ranged between 100,000 to 800,000 in different years (Patnaik et al., 2001; Tripathy, 2002). Although multiple mass nesting events have been reported at Gahirmatha, there are also records of failure (Dash & Kar, 1990; Patnaik & Kar, 2000; Shanker et al., 2004). At Gahirmatha, the recent trend on mass nesting has occurred either in alternative years or apparently absent in some consecutive years (Pandav & Choudhury, 2000; Draft Final Report WII, 2011). For instance, the failure of mass nesting in 1997, 1998 and 2008 at Gahirmatha is a cause for concern due to drastic changes in nesting beach profile (Pandav & Choudhury, 2000; Shanker et al., 2004) The mass nesting has been a continuous event since its discovery in 1974 until 1982. The Olive Ridley turtles can detect both the angle and intensity of the earth's magnetic field. Using these two characteristics, a sea turtle may be able to determine its latitude and longitude, enabling it to navigate virtually anywhere. Early experiments seem to show that sea turtles have the ability to detect magnetic fields. It is believed that hatchlings imprint the unique qualities of their natal beach while still in the nest and/or during their trip from the nest to the sea. Beach characteristics used may include smells, low-frequency sound, magnetic fields, the characteristics of seasonal offshore currents and celestial cues. Younger female turtles may follow older, experienced nesting turtles from their feeding grounds to the breeding site[2]. In March 2020, it was observed by the Forest and Wildlife Department people that the Olive Ridley sea turtles came out for mass nesting in the daytime which occurred after seven years gap[3]. Usually, the beaches are swamped with crawling Olive Ridley turtle babies, making their first trek towards the ocean. It is estimated that one hatchling survives to reach adulthood for every 1,000 hatchlings that make it to the sea[4].

The nesting process consists of several stages. The female turtle emerges from the sea at night and ascends the beach, searching for a suitable nesting site (somewhere dark and quiet). Once at the chosen nesting site, she begins to dig a body pit by using all four flippers. She removes the dry surface sand beneath her, which will later be used to cover the egg chamber. Once she has created a body pit, she begins to dig an egg chamber using her rear flippers, alternating between the right and left flippers to scoops out the damp sand. When she can reach no deeper, she pauses and begins contractions, her rear flippers rising off the sand. Soon she begins laying eggs. Following each contraction, the female turtle will drop between one and four eggs in quick succession. The eggs will almost fill the chamber. Once her clutch is complete, she closes the nest using her rear flippers in a similar way to digging her egg chamber, just in reverse[5]. There is no such evidence or research papers found to establish that the sea current and temperature can drive turtles to a beach for mass nesting.

Historically, mass nesting has taken place along the 10 km of mainland coast in the Bhitarkanika Wildlife Sanctuary. However, from 1989 nesting became restricted to a 4 km long-isolated sand bar projecting into the Bay of Bengal. The super cyclone in 1999 fragmented the 4 km nesting beach into two islets namely Nasi-I & Nasi-II. The Defense Research and Development Organization (DRDO) have reported that mass nesting now takes place along a section just 900m long beach of the Wheeler Island, which is located at the tip of the sand bar.

[1] https://www.conserveturtles.org/information-sea-turtles-general-behavior/
[2] https://oliveridleyproject.org/ufaqs/how-are-sea-turtles-able-to-return-to-the-same-beach-to-nest
[3] https://india.mongabay.com/2020/04/olive-ridleys-day-nest-in-odisha-after-seven-years-but-no-link-to-lockdown-say-experts/
[4] https://www.hindustantimes.com/travel/ridley-me-this-the-nesting-of-odisha-s-olive-ridley-turtles-is-an-experience-of-a-lifetime/story-artAuWttI0GUbJXwbfYXhP.html
[5] https://www.conserveturtles.org/information-sea-turtles-frequently-asked-questions/#2

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Oct)	Increase by 3.9% (i.e., 48.2mm, from 1262.2 to 1310.4 mm) by 2050s. A more significant increase for immediate upstream areas in the catchment (11.2% or 140mm). This increase is likely to be concentrated in more intense events	Very Low	Very Low	Very Low	**Direct impacts[6]:** • An increase in rainfall of 48.2mm during the monsoon season will not have much impact on Olive Ridley turtles as they arrive post-monsoon. • Neither the sandy beach nor the eggs will be affected due to the increase in the rainfall of 48.2 mm during the monsoon.	Very High	Very Low
Decrease of rainfall during the dry seasons i.e., Winter (Nov-Jan), Summer (Feb-May)	Decrease by 8.2% (i.e., -13.3mm, from 167.0 to 153.7 mm), during the summer by 2050s. Slightly decrease by 5.5% (i.e., -3.7mm), during the winter.	Low	Medium	Medium	**Direct impacts:** • The decrease in rainfall during the dry season will not have much impact on Olive Ridley turtles as they need temperature for hatching. But if the temperature will go up and there will not be any rain to minimize the temperature during March and April when the eggs of the turtle are on the beach, then it may produce single-sex hatchlings. (-ve)	Low	Medium
TEMPERATURE							
Increase in temperature during Summer (Feb-May)[7]	Average maximum temperature increase from 33.5 to 35.6ºC (increasing by 2.1ºC).	Medium[8]	High[9]	High[10]	**Direct impacts:** • The mass nesting site is vulnerable to changes in temperature under high nest density conditions that make embryo development impacted especially when incubation temperatures fluctuate around 3°C or less than the pivotal temperature may result in the exclusive production of a single-sex.[11](-ve)	Medium	High

[6] The overall increase in rainfall will have positive as well as negative potential effects on the Ramsar site. The adaptation measures will primarily focussed on reducing the negative effects.

[7] This is an extreme season with limited rainfall and high temperatures – which tends to place stress on the forests and associated species. It is the flowering season for many plants preparing for propagation during the wet season so it is a sensitive period which would be affected by increasing temperatures.

[8] Olive Ridley needs 30ºC to 34ºC temperature for successful incubation between February to April and increase of 1.6ºC will have medium impact on them.

[9] The Exposure to the increased temperature will be high as the sandy beaches are mostly having no tree sheds.

[10] When the temperature will go up during the mass nesting season, the eggs may produce single sex hatchlings.

[11] https://www.researchgate.net/profile/Roldan-Valverde/publication/237978322_Field_lethal_incubation_temperature_of_olive_ridley_sea_turtle_Lepidochelys_olivacea_at_a_mass_nesting_rookery/links/551b12fd0cf2bb75407889c4/Field-lethal-incubation-temperature-of-olive-ridley-sea-turtle-Lepidochelys-olivacea-at-a-mass-nesting-rookery.pdf?origin=publication_detail

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
					• The quality and performance of Olive Ridley hatchlings will be poor in case of crawling speed, self-righting time and self righting propensity that may lead to high mortality rates while travelling back to sea due to the rise in temperature[12].(-ve) **Indirect impacts:** • The female turtles may avoid coming to the mass nesting beach in future if they fail to lay eggs on a nesting site due to any reason[13]. (-ve)		
Increase of temperature during Winter (Nov-Jan)	Winter will be warmer with an increase of 2.0ºC by 2050s (from 27.6ºC to 29.6ºC) in average maximum temperature.	**Low**[14]	**High**[15]	**Medium**	**Direct impacts:** • The increase in temperature during winter may lead to early nesting by the turtles and fail to get proper temperature between approximately 45 to 60 days of incubation period after laying eggs[16]. (-ve)	**Medium**	**Medium**
EXTREME EVENTS							
Sea level rise	Sea level rise projected at 0.5 m by 2040 for the Ramsar site coastline[17]. Over extraction of groundwater is leading to	**Very High**[18]	**Very High**[19]	**Very High**	**Direct impacts:** • Due to sea-level rise, high tides near the shoreline may disturb the congregation and mating of the Olive Ridley turtles. (-ve)	**Very Low**[20]	**Very High**

[12] If the hatchlings don't make it to the ocean quickly, many hatchlings will die of dehydration in the sun or be caught by predators like birds and crabs. The hatchlings usually emerge from their nest at night or during a rainstorm when temperatures are cooler. https://www.conserveturtles.org/information-sea-turtles-general-behavior/and https://www.researchgate.net/publication/257377570_The_effect_of_incubation_temperature_on_hatchling_quality_in_the_olive_ridley_turtle_Lepidochelys_olivacea_from_Alas_Purwo_National_Park_East_Java_Indonesia_Implications_for_hatchery_management

[13] The female turtles tend to come back to the same beach where they hatched earlier to lay new eggs.

[14] The turtles will be inside the sea water hence having low impact on them.

[15] The turtles may be instigated for mass nesting before time (March-April).

[16] The winter season continues till mid-Feb and the temperature may be less for successful hatching.

[17] CWC, 2015. Operational Research to Support Mainstreaming Integrated Flood Management in India under Climate Change Vol. 5b Modelling Report Brahmani-Baitarani.

[18] Sea level rise will bring high tides which may wash away the eggs and or immature hatchlings at times as the incubation period of approx. 45-60 days.

[19] In case the Olive Ridley turtles will face any trouble in mass nesting due to high tides and may change the place before laying eggs.

[20] When the turtles are ready to lay eggs, they save energy by floating in stand still position near to the coastline and in case there will be high tide, they may not be in a position to adapt the situation.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
	ground subsidence of the mangrove area (team needs to assess groundwater levels and extraction and subsidence) The increased tidal height will erode and inundate the sandy beach leads to a reduction in the mass nesting place available for Olive Ridley turtles.				• Over reduction in sandy shoreline area due to erosion of sand-dunes and beach leads to a reduction in the availability of mass nesting area for Olive Ridley turtles. (-ve) **Indirect impacts:** • The Olive Ridley Sanctuary area of Gahirmatha may lose its importance as the highest mass nesting place in the world. Reduced conservation values for Olive Ridley sea urtles. (-ve)		
Cyclones	Very high risk of increased frequency of cyclones[21].	**Very High**	**Very High**	**Very High**	**Direct impacts:** • Cyclones with severe intensity will damage the sandy beach that may further be submerged and restrict the Olive Ridley turtles from mass nesting. (See the Cyclone Vulnerability Map attached below) (-ve) • The anticipated increase in cyclone occurrence and severity will lead to the poor congregation and breading during the pre-nesting season in the month of November and December[22]. (-ve) **Indirect impacts:** • The decreased congregation and mating may result in a decrease in the number of eggs laying in the mass nesting sites and lead to a drastic reduction in the number of hatchlings. (-ve)	**Very Low**	**Very High**

[21] 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.

[22] The cyclone season in Odisha coast is considered during October to December and April to June..

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Storm surge	Moderate to high risk of up to 5 m storm surge.[21] (Tsunami prediction with a tidal range between 2.5 to 3 m high tidal surge and run-up between 1.0 to 2.0 m).	**High**[23]	**High**	**High**	**Direct impacts:** • Moderate to high risk of storm surge (up to 5 meters) may result in the death of turtles that are normally congregated close to the shoreline waiting for mass nesting breading. (-ve) • The sand-dunes and beaches will be eroded due to tidal surges and the nesting site will be unsuitable for mass nesting of turtles due to mud layers on the top of the sands. (-ve) • The return tidal wave water may wash away the eggs from the nesting sites and the number of hatchlings may reduce drastically if it takes place during the incubation period. (-ve) **Indirect impacts:** • The female turtles may avoid coming to the mass nesting beach in future if they fail to lay eggs on a nesting site due to any reason[24]. (-ve)	**Low**	**High**

[23] In case it happens during the incubation and or mass nesting period the impact will be high

[24] The female turtles tend to come back to the same beach where they hatched earlier to lay new eggs.

Annex 2.4.1 - 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 1 *Determining impact score from sensitivity and exposure*

Annex 2.5 - Vulnerability Assessment Matrix for Fisheries

ASSET NAME: FISHERIES

ASSET DESCRIPTION: The availability of fish has an impact on the ecosystems in Bhitarkanika Ramsar Site. Mangrove ecosystems serve as vital nursery grounds for the economically important nearshore fish and shellfish species. Snedaker (1984) estimated that more than 90% of near-shore marine species were found in the mangroves during one or more parts of their life cycles. It has been proved by many studies that the mangrove ecosystem contributes substantially to offshore fisheries.

Fishing (freshwater, brackish water and marine), aquaculture (Prawns) are the main livelihood activities of the people in Ramsar site. About 110 villages depend on fisheries as their secondary livelihood. This also serves the food security of half a million migratory waterbirds. Fish species diversity has been reduced although fish production increased. Despite a ban period imposed by the forest and marine department for conservation of aquatic species, illegal river and marine fishing are continuing in parts of restricted areas. Fishermen are not abiding by the regulation imposed by the government. Irrespective of the restrictions of government, the fishermen are using small mesh-size nets that catch the small size fishes impacts the growth of the fish population in general. In the Ramsar Site aquaculture ponds are increasing[1]. Fishery Department, Kendrapara District within Ramsar Site implements various livelihood schemes related to fish production and marketing. Forest Department controls the fishing in the restricted area. The Indian Fishery Act for the protection of the Ramsar site - departments like Forest & Wildlife, Marine Fishery, inland Fishery, Water resource and revenue facilitate the implementation of these laws for the protection of Ramsar Site.

There are impacts on fisheries and mangrove ecosystems due to the polluted effluents entering from the catchment areas into the Ramsar Site, sources are from industries, mining areas, aquaculture farms, agriculture chemicals, domestic pollution, etc. Climate Change has an impact on fish populations and species diversity.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Oct)	Increase by 3.9% (i.e., 48.2mm, from 1262.2 to 1310.4 mm) by 2050s. A more significant increase for immediate upstream areas in the catchment (11.2% or 140mm). This increase is likely to be concentrated in more intense events	**Low**	**Low**	**Low**[2]	**Direct impacts**[3]**:** • Would increase the number of freshwater fish in rivers and creeks (+ve) • Huge amounts of water flowed from the catchment into creeks would bring organic materials and nutrients (used in agriculture fields). This has the potential to lead to fish kills. (-ve)	**Very High**[4]	**Low**

[1] Cooperation needed from the Fisheries department, Orissa State for controlling prawn culture in an eco-sensitive zone, which would also impact the native fish population due to effluents and excess drawl of water.
[2] The ban period is June and July (monsoon season) for the freshwater fish breeding period. This ban is for trawlers and motorized boats only, not for country boats.
[3] The overall increase in rainfall will have positive as well as negative potential effects on the Ramsar site. The adaptation measures will primarily focussed on reducing the negative effects.
[4] The fisheries department in implementing various livelihood scheme related to fish production and marketing in the Ramsar site. Capacity building of fish farmers.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
					Indirect impacts: • Improve the conditions for mangroves health and extent, so the fish habitats improve (+ve) • Heavy rainfall and increased water level reduces the fish catch as during rainy season fish migrate to the newly inundated areas and shallow peripheries and escape from fishing gear (-ve)		
Decrease of rainfall during the dry seasons i.e., Winter (Nov-Jan), Summer (Feb-May)	Decrease by 8.2% (i.e., -13.3mm, from 167.0 to 153.7 mm), during the summer by 2050s. Slightly decrease by 5.5% (i.e., -3.7mm), during the winter.	**High**	**High**	**High**[5]	**Direct impacts:** • Less freshwater in rivers, creeks, and ponds, will impact fish species and availability in numbers as they will be more easily consumed by dependent birds and animals (-ve) • The pollution level in the water bodies increases impacting the fisheries habitats (-ve) **Indirect impacts:** • Reductions in fish populations impact catch with significant livelihood effects, exacerbated by current trends in overfishing. (-ve)	**Low**[6]	**High**[7]
TEMPERATURE							
Increase of temperature during the Monsoon (Jun-Oct)	Average maximum temperature increase from 31.6 to 33.5ºC (increasing by 1.9ºC).	**Low**	**Medium**	**Medium**	**Direct impacts:** • Changes in temperature can produce shifts in fish and aquatic species composition (-ve) **Indirect impacts:** • Reducing fish catch with impacts on livelihoods (-ve)	**Medium**	**Medium**

[5] In spite of decrease in rainfall, the increase in rainfall during monsoons will not reduce the water levels in water bodies much.
[6] In the case of drought the adaptive capacity of fishes is normally low.
[7] The Indian Fishery Act for the protection of the Ramsar site. Departments like Forest & Wildlife, Marine Fishery, inland Fishery, Water resource and revenue facilitate the implementation of these laws for the protection of Ramsar Site.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase in temperature during Summer (Feb-May)[8]	Average maximum temperature increase from 33.5 to 35.6ºC (increasing by 2.1ºC).	**Medium**	**High**	**Medium**	**Direct impacts:** • Ocean acidity would lead to a reduction of zooplankton and affect the availability of marine fish. (-ve) • The availability of fish is reduced by poor water quality and increased temperature of water bodies. (-ve) • Drought conditions and less water availability will reduce the fish population (-ve) **Indirect impacts:** • Reducing fish catch with impacts on livelihoods (-ve)	**Medium**	**Medium**
Increase of temperature during Winter (Nov-Jan)	Winter will be warmer with an increase of 2.0ºC by 2050s (from 27.6ºC to 29.6ºC) in average maximum temperature.	**High**	**High**	**High**[9]	**Direct impacts:** • The lack of oxygen in waters due to the increase in temperature leads to less existence of fish and aquatic life[10]. (-ve)	**Medium**[11]	**High**
EXTREME EVENTS							
Sea level rise	Sea level rise projected at 0.5 m by 2040 for the Ramsar site coastline[12].	**Medium**	**Medium**	**Medium**	**Direct impacts:** • Habitat for spawning and growth of marine and brackish water fish will be reduced (-ve) • Freshwater fish will tend to be replaced by brackish water fish as sea-level rise will lead to water salinity. (-ve)	**Low**	**High**

[8] This is an extreme season with limited rainfall and high temperatures – which tends to place stress on the forests and associated species. It is the flowering season for many plants preparing for propagation during the wet season so it is a sensitive period which would be affected by increasing temperatures.

[9] Fishermen used to catch Telia fish (20-25 kgs each) during the winter season, as they have been experiencing the winter duration is reducing and there is increase in temperature during winter, Telia fish are found less.

[10] As an example, Bhanja Prashad Village, Ramsar site, fishermen used to catch Telia fish about 20-25 kg per day in the past during winter seasons, as they have been experiencing the winter duration is reducing and there is an increase in average temperature during winter, these fishes are less visible.

[11] Less water conditions and increase in temperature makes fishes less adaptive.

[12] CWC, 2015. Operational Research to Support Mainstreaming Integrated Flood Management in India under Climate Change Vol. 5b Modelling Report Brahmani-Baitarani.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Cyclone	Very high risk of increased frequency of cyclones[13].	**High**	**Medium**	**High**	**Direct impacts:** • Cyclones will impact the fish habitats and there will be fewer fish with the increased number of cyclones. (-ve) **Indirect impacts:** • The fishing fleet will be prevented from going to sea during cyclones and may be damaged (-ve) • Losses of fishing days, boats and gear, Fishing communities will be displaced, and their livelihood will be impacted (-ve)	**Low**	**High**
Storm Surge	Moderate to high risk of up to 5 m storm surge.[13].	**Medium**	**Medium**	**Medium**	**Direct impacts:** • The saltwater intrusion into the habitat will affect the fish diversity and availability (-ve) **Indirect impacts:** • Fishing communities will be displaced, and their livelihood will be impacted (+ve)	**Low**	**High**

[13] 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.

Annex 2.5.1 - 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 2.6 - Vulnerability Assessment Matrix for Tourism

ASSET NAME: TOURISM

ASSET DESCRIPTION: Bhitarkanika National Park (BNP) was declared as a National Park on 16 September 1998. It obtained international importance as Ramsar site on 19th August 2002. Bhitarkanika tourism has got attraction for the Natural lush green mangrove forest, largest saltwater crocodile sanctuary, Asia's largest mixed-species heronry, (Bagagahana & Matha-Adia), numerous wild animals in mangrove forests and unique vast nesting ground beach of Olive Ridley (Gahirmatha). The National Park is open for tourism from January to April and August to December, however, the peak season for tourism is from October to February. Natural disasters like floods and cyclones affect tourism for a short period of time. Good disaster preparedness at the government and community level has prevented the damage to life and livelihood assets to a great extent. Tourism Department has initiated echo-tourism camps in Bhitarkanika during January month every year. Tourism Department has initiated echo-tourism camps in Bhitarkanika during January from 2020. Annually around 50,000 tourists visit Bhitarkanika.

Tourism is increasing every successive year (only with exception of fewer tourists due to the Covid pandemic in 2020-2021). The livelihoods related to tourism are increasing such as hospitality services - restaurants, canteens, lodging, homestay, boating, shops, local guides, etc. However, tourism in Bhitarknika is a seasonal/ secondary livelihood for a very small population from 20-25 villages that are close to the sanctuary area. But the growth of hotel and restaurants service is very slow as many of the tourists are floating population who return on the same day after visiting.

Echo-tourism operator: The knowledge of Echo-tourism operators on the safe disposal of garbage is poor. Tourism operators who own the hotel and restaurants closure to the National park have been disposing of the garbage including polythene wrappers and plastic bottles in backward open fields or burning the garbage which is more harmful to the environment. At time of heavy rain and flooding situation, all the garbage are getting into the river/ creeks nearby and causing pollution.
Forest Department has taken some good initiatives in the management of plastic disposal within the sanctuary area by introducing a security deposit from tourists for using plastic bottles and collecting the used plastic bottles from tourists at the returning time. However, this management is practised at the main entry point of Bhitarkanika National Park at Dangamal, not in all entry points.

Echo-Development Committee (EDC): EDC has a big role in influencing tourism by influencing the behaviour of the community towards pollution in the Ramsar site. Presently the awareness level of the community is very low to understand how domestic garbage management and pollution at sea and river level contributes to damage of echo-system. Tourism operators can play a big role in sensitizing the tourist on pollution and promoting the rule and regulations imposed by the government for the protection of the environment. The community is also not taking much interest in the joint forest management process as they are not benefiting from the activities. Few Eco-Development Committees (EDCs), which are located closer to the national park are getting some benefits from ecotourism, the majority of the EDCs are dysfunctional. Forest Department has very limited funds to create scope for all EDCs to participate in the process of community-based conservation activities.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
PRECIPITATION							
Increase of rainfall during Monsoon (Jun-Oct)	Increase by 3.9% (i.e., 48.2mm, from 1262.2 to 1310.4 mm) by 2050s. A more significant increase for immediate upstream areas in the catchment (11.2% or 140mm). This increase is likely to be concentrated in more intense events	**Medium**[1]	**Medium**[2]	**Medium**	**Direct impacts:** • A fewer number of tourists visit during monsoon season as Forest Department restricts the tourist visit up to 31st July. (-ve) • The tourism sector is affected for a few days as it starts generally from October month onwards. (-ve) • Roads are less commutable due to monsoon rains and inundation (-ve) **Indirect impacts:** • Loss of income for government and community (-ve)	**Very High**[3]	**Low**
Decrease of rainfall during the dry seasons i.e., Winter (Nov-Jan), Summer (Feb-May)	Decrease by 8.2% (i.e., -13.3mm, from 167.0 to 153.7 mm), during the summer by 2050s. Slightly decrease by 5.5% (i.e., -3.7mm), during the winter.	**Very Low**[4]	**Very Low**	**Very Low**	**Direct impacts:** • Increase in the number of tourists to the national park. (+ve) **Indirect impacts:** • Good income for community and government (+ve) • Increase in pollution in sanctuary area due to high inflow of tourist (-ve)	**Very High**	**Very Low**
TEMPERATURE							
Increase of temperature during the Monsoon (Jun-Oct)	Average maximum temperature increase from 31.6 to 33.5ºC (increasing by 1.9ºC).	**Very Low**[5]	**Very Low**[6]	**Very Low**	**Direct impacts:** • Not much impact on tourism as up to August visit of tourists is very less. (+ve) • By October the temperature start declining, which is pleasant for tourist. (+ve)	**Very High**[7]	**Very Low**

[1] Kendrapada district is coming under a high flood zone area, but Bhitarkanika is close to the seacoast so floodwater recedes very first.
[2] As tourist season starts in October, so sensitivity is medium.
[3] Odisha Disaster management Early warning system is strong, so community get prior information.
[4] Few days of rainy day, so exposure is very low.
[5] Exposure to 33.5ºC temperature for tourists is very low.
[6] Tourist season starts in October, so tourism will not be affected much.
[7] In case of any significant change in weather, tourism operators/tourist gets prior information.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
TEMPERATURE							
Increase in temperature during Summer (Feb-May)[8]	Average maximum temperature increase from 33.5 to 35.6ºC (increasing by 2.1ºC).	**Medium**[9]	**Medium**[10]	**Medium**	**Direct impacts:** • Due to high temperature, animals (wild animals and crocodiles will not be visible for tourist sightings, so less attraction for tourists. (-ve) • Increases in selling soft drinks/ tender coconut being managed by community members(+ve) • No birds available for sighting may lead to less attraction for bird watching tourists visiting Bhitarkanika. (-ve)	**High**[11]	**Medium**
Increase of temperature during Winter (Nov-Jan)	Winter will be warmer with an increase of 2.0ºC by 2050s (from 27.6ºC to 29.6ºC) in average maximum temperature.	**Very Low**	**Very Low**	**Very Low**	**Direct impacts:** • The peak time for tourism (+ve) • Temperature is ambient for sanctuary visit (+ve)	**Very High**[12]	**Very Low**
EXTREME EVENTS							
Sea level rise	Sea level rise projected at 0.5 m by 2040 for the Ramsar site coastline[13].	**Very High**[14]	**High**[15]	**Very High**	**Direct impacts:** • Coastline erosion and change in bio-diversity of mangroves will contribute to the loss the attractiveness of the Bhitarkanika site as the major habitat. (-ve) • Visitors to Bhitarkanika will be less (-ve) • Increase of fish availability which may lead to increase in migratory bird(+ve)	**Low**[16]	**Very High**

[8] This is an extreme season with limited rainfall and high temperatures – which tends to place stress on the forests and associated species. It is the flowering season for many plants preparing for propagation during the wet season so it is a sensitive period which would be affected by increasing temperatures.

[9] 35.6ºC is a medium exposure for tourists.

[10] With an increase of temperature during March, tourists visit gradually reduce.

[11] Up to 35.5ºC will not impact tourists.

[12] Temperature is quite suitable for tourist and the Tourism Department make additional arrangement for Nature camps.

[13] CWC, 2015. Operational Research to Support Mainstreaming Integrated Flood Management in India under Climate Change Vol. 5b Modelling Report Brahmani-Baitarani.

[14] Bhitarkanika is highly exposed to sea-level rise and the impact is already visible in Ramsar sites, as 6 villages in Satabhaya is already submerged in the sea.

[15] As tourism is very much linked with the bio-diversity of Bhitarkanika, when the bio-diversity is highly sensitive, so also the tourism is highly sensitive.

[16] Forest Department has initiated the process of adaptation activities to prevention of sea-level erosion, but a long way to go.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
					Indirect impacts: • Reduce income of local community(-ve) • Tourism importance may lose. (-ve) • Reduce in agricultural land • As the male population is mostly engaged in the tourism sector directly, increased impact on tourism will increase migration among males. • Increased work pressure on single women at village level to manage household activities and livelihood and rearing of children. • Single women with children will face more difficulties during successive disasters to protect their livelihood and shelter		
Cyclone	Very high risk of increased frequency of cyclones[17].	Very High	High[18]	Very High	**Direct impacts:** • Damage of Tourism assets like boats, petty shops. (-ve) • Disruption of communication and damage to roads. (-ve) • Temporary suspension of tourist visits. (-ve) • Damage of Mangroves will affect the birds nesting which may lead to sift of the place of nesting resulting in less attraction for tourists. **Indirect impacts:** • Loss of business for a temporary period. (-ve) • The increasing cost of tourism in reconstruction. (-ve)	Low[19]	Very High

[17] 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.

[18] Though Some structures like Lodging facilities are Cyclone resistance, but maximum assets related to tourism are highly sensitive to cyclone because of its design.

[19] Low capacity tourism sector of protection of asset, as many of petty shops and restaurants structures are not cyclone resilient.

Threat category	Details of threat	Exposure	Sensitivity	Impact level	Impact summary	Adaptive capacity	Vulnerability
EXTREME EVENTS							
Storm Surge	Moderate to high risk of up to 5 m storm surge[13].	**High**[20]	**High**[21]	**High**	**Direct impacts:** • Damage to Tourism assets like boats, petty shops. (-ve) • Damage of mangroves will reduce the attraction of tourists for visit for a temporary period. (-ve) • Loss of income of tourism sector (-ve) **Indirect impacts:** • Damage to local livelihood and shelter will build pressure on natural resources of Ramsar site (-ve) • Untreated sewage, solid waste pollution generated by ~50k tourists is a concern to the Ramsar site. (-ve)	**Low**[22]	**Very High**

Photo credit: WISA

[20] Intensity of storm surge is high.

[21] Sensitivity is high as Bhitarkanika is 2 km away from the sea.

[22] Entire tourism sector including tourists, assets and infrastructures will be affected.

Annex 2.6.1 - 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 – LIST OF ADAPTATION PLANNING MATRICES FOR BHITARKANIKA MANGROVES

The matrices are attached as complementary material.

Table 29 *Adaptation Matrices*

Target asset	Attached file
Catchments	AAS2010-REP-003-02 Final Report Bhitarkanika (Annex 3.1 AP_Catchment).docx
Mangrove habitats	AAS2010-REP-003-02 Final Report Bhitarkanika (Annex 3.2 AP__Mangroves).docx
Saltwater Crocodile	AAS2010-REP-003-02 Final Report Bhitarkanika (Annex 3.3 AP_Crocodiles).docx
Olive Ridley Turtle	AAS2010-REP-003-02 Final Report Bhitarkanika (Annex 3.4 AP_OliveRidley).docx
Fisheries	AAS2010-REP-003-02 Final Report Bhitarkanika (Annex 3.5 AP_Fisheries).docx
Tourism and recreation	AAS2010-REP-003-02 Final Report Bhitarkanika (Annex 3.6 AP_Tourism).docx

Photo credit: TARUOO

Annex 3.1 - Adaptation Planning Matrix for the Catchment

ASSET NAME: CATCHMENT - RIVER BASINS OF BRAHMANI AND BAITARANI INFLUENCING BHITARKANIKA RAMSAR SITE

ASSET DESCRIPTION: Bhitarkanika Ramsar Site is in the deltaic region of Brahmani River (799 km length) and Baitarani River (355 km length) systems. The catchment area (Longitude 83° 55' to 87° 3' E; Latitude 20° 28' to 23° 38' N) is the zone of influence for the Ramsar Site located at the tail end of the basin. Brahmani River Catchment area is one of the major inter-state east-flowing rivers amongst the Peninsular river in India. The basin covers Jharkhand, Chhattisgarh and Odisha states and drains an area of 39033 km^2. A major portion of the Baitarani basin lies in Odisha, except a small portion which lies in Jharkhand, it drains an area of 10,982 km^2. The combined basin consisting of Brahmani, and Baitarani extends over an area of 51822 km^2. In which, Bhitarkanika Ramsar Site area is about 650 Sq.km area. There are over 42 dams constructed and 9 projects under construction and also a few proposed, in the catchment area of these two rivers.

Salinity has been increasing due to human activities such as (1) Rengali dam and several other dams, which causes less freshwater flowing into the Brahmani river system, (2) Siltation of river mouths due to reduced inflows, (3) Increase in water consumption for irrigation, aquaculture, tourists, and requirement of people in the villages. This is the main cause for significant changes in the density and distribution of plants and key species - mangroves, crocodiles, turtles, and birds. The water drawn from the wetland for aquaculture ponds and the polluted drainage water from the ponds entering the wetland creeks and rivers is a concern.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Decrease of rainfall during the dry season (Feb-May) – **High**	• Increase in pollution of the surface water and groundwater. The sources of contamination are domestic sewage, garbage, soil erosion, mining areas runoff and anthropogenic activities with extensive recreational use of the streams and the river. (-ve)	Compliance of all laws and implementation to prevent water pollution from the respective sources of pollution; Creating awareness to communities to prevent pollution – Odisha state pollution control board and government departments representing the entities causing pollution should control pollution.	**Medium[1]**	**Medium[2]**	**Medium**

[1] The pollution sources are many (industrial, mining, sewerage, agriculture, etc) and the catchment area is large (51822 km2).
[2] Pollution would increase as the industrialization. Urbanisation in the catchment area increases.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
Increase in temperature during summer/ pre-monsoon (Feb to May) – **High**	• High surface temperature also increases evapotranspiration, increases demand for irrigation water and other water supply in the catchment.	Water for drinking and ecosystem services should be ensured; water use efficiency, irrigation scheduling should be planned and implemented as per the water availability – Panchayati Raj and Drinking Water Department, Water Resources department and Forest, Environment and Climate Change Department should discuss the modalities and implement.	**High**[3]	**Medium**[4]	**Medium**
	• Water pollution will be high during summer (-ve)	Compliance of all laws and implementation to prevent water pollution from the respective sources of pollution; Creating awareness to communities to prevent pollution – Odisha state pollution control board and government departments representing the entities causing pollution should control pollution.	**Medium**[5]	**Medium**[6]	**Medium**
Increase of temperature during the winter (Nov –Jan) - **High**	• The water bodies in the catchment areas would dry quickly (-ve)	Ensure minimum flows in rivers and streams, and dead storage in the water bodies through proper management of reservoirs in the catchment area – Water Resources Department should ensure through planning and management.	**High**[7]	**Medium**[8]	**Medium**
EXTREME EVENTS					
Cyclones - **High**	• There will be floods in the catchment area (-ve)	The existing irrigation and catchment area development projects and planned future projects, and monitoring of hydrology of basin and management would control the flood intensity and lessen the damage – Water Resources Department of Odisha should ensure.	**Medium**[9]	**High**[10]	**High**

[3] As drinking water and water for ecosystem services (minimum desired flows in the river system and dead storage of water in reservoir) are important, the priority would be given by the government and implementable with cooperation of the relevant departments.
[4] Efficient water management especially for drinking water and ecosystem services would benefit both people and ecosystem. It would be difficult during drought period to implement. This is a continuous process to be adopted.
[5] The pollution sources are many (industrial, mining, sewerage, agriculture, etc) and the catchment area is large (51822 km2)
[6] Pollution would increase as the industrialization. Urbanisation in the catchment area increases.
[7] As drinking water and water for ecosystem services (minimum desired flows in the river system and dead storage of water in reservoir) are important, the priority would be given by the government and implementable with cooperation of the relevant departments.
[8] Efficient water management especially for drinking water and ecosystem services would benefit both people and ecosystem, it would be difficult during drought period to implement. This is a continuous process to be adopted.
[9] It is involving huge costs, environmental clearances, rehabilitation of the affected communities etc., for construction of the dams, reservoirs, and control systems. However, monitoring the weather, climate extremes and climate change projects are feasible.
[10] The structures and systems established would benefit over long periods and effective as already proved. However floods are not 100% controllable as there would be many other reasons for flooding as it happened in Kerala Floods in 2018.

Annex 3.1.1 - 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

Annex 3.2 - Adaptation Planning Matrix for the Catchment

ASSET NAME: CROCODILES

ASSET DESCRIPTION: Bhitarkanika National Park of Odisha has the largest habitat of the endangered estuarine saltwater crocodiles in India. Brackish wetland and natural lush green mangroves are the peaceful abode of the crocodile in Bhitarkanika. As per crocodile estimation data of Forest and environment department, Rajnagar division, Kendrapada, the population of crocodiles has increased from 1498 in 2008 to 1798 in 2020. The average survival rate of hatchlings is 1% to 1.5%. The life span of saltwater crocodile range 70-100 years.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
Increase in temperature during summer/ pre-monsoon (Feb to May) – **Very High**	Young saltwater crocodiles will take shorter dives in the water and remain in the land for a longer period of time which will increase the risk of being attacked by predators. The mortality of young crocodiles will be high.	Artificial rearing of crocodile hatchlings three to four years- by Forest, Environment and Climate Change Department[1]	High[2]	High	High
	Shrinking of crocodile habitat as some creeks linked to Khola creek get dried up.	Excavation of the sub-creeks for maintaining the water level required for crocodiles – to be undertaken by Forest, Environment and Climate Change Department.	High[3]	Medium[4]	High
	Crocodiles will migrate to cooler places out of the sanctuary area	Maintaining density of Mangrove close to mudflat areas in the in order to maintain the temperature in the creeks that restrict/minimize migration of crocodiles to outside sanctuary area – by Forest, Environment and Climate Change Department	High[5]	Very High[6]	High
EXTREME EVENTS					
Sea level rise - **High**	Submergence of basking and nesting area of crocodile	Crocodiles to be moved or relocated in the higher areas and towards inland within the Ramsar Site	High	High	High

[1] It is already a part of the management plan of Bhitarkanika.
[2] Forest and Wildlife Departments have been facilitating artificial hatching and rearing of crocodile in Bhitarkanika National park
[3] Creak excavation is a part of the management plan of Forest Department.
[4] Every two three years excavation activity need to be repeated, as silt deposit continues with tide and flood.
[5] Forest Department can maintain the density of mangrove forest at the creak side.
[6] Mangroves by the creak side will be well protected from human being due to the habitation of crocodiles.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
Storm Surge - **Very High**	Crocodile nests/eggs will be wash out leading to a reduction in crocodile population	Plantation of mangroves in the coastline in front of the sanctuary to minimize the impact of storm surge– by Forest, Environment and Climate Change Department	High[7]	High	High
		Construction of saline embankment to protect the sanctuary – by Water Resources department	Very High[8]	Very High	Very High
	Juveniles will get out of the sanctuary area to wider catchment area/sea/ human habitation due to extensive flooding for a temporary period.	Plantation of mangroves in the coastline in front of the sanctuary to minimize the impact of storm surge – by Forest, Environment and Climate Change Department	High[9]	High[10]	High
		Construction of saline embankment to protect the sanctuary – by Water resources department in coordination with Forest, Environment and Climate Change Department	Very High[11]	Very High	Very High
		Awareness generation of community members on information and coordination mechanism to protect the crocodiles- by Forest, Environment and Climate Change Department	Very High[12]	Very High	Very High
	Potential increase of Human and crocodile conflict	Awareness generation of community members on information and coordination mechanism to protect the crocodiles – by Forest, Environment and Climate Change Department	Very High[13]	Very High[14]	Very High

[7] Forest Department has been continuing the plantation activities in the coastline.
[8] Water Resource Department has planned for 380 km Saline embankment along with massive plantation of estimated cost 1944 crore (The economic times, 30th May 2021).
[9] Forest Department is continuing the plantation in the coastline.
[10] Forest Department need to involve community in plantation program to make it more sustainable.
[11] Resource Department has planned for 380 km Saline embankment along with massive plantation of estimated cost 1944 crore (The economic times, 30th May 2021).
[12] Community sensitization program is highly important to be a part of the management plan.
[13] Forest and Wild life departments have the potential to include community based activities in the management plan.
[14] Community awareness and involvement will make the protection program more sustainable.

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 Mangroves

ASSET NAME: MANGROVES

ASSET DESCRIPTION: 29 true mangrove species and 72 mangrove associates from different mangrove forest sites of the Bhitarkanika National Park. The classified true mangroves have adaptation mechanisms to resist the physiologically dry surrounding environment and they generally form pure stands in Bhitarkanika National Park. The Forest Survey of India-2013 report highlighted a drop in mangrove cover in the State by nine square km over 2011-from 222 km^2 to 213 km^2. In Kendrapara district alone, where most of Bhitarkanika is located, the drop was by 4 km^2. Since 2014 Forest Dept. has been planting, so the extent of mangrove cover is increasing, but density is reducing. The baseline shows a trend in salinity increasing at all stations. The changes in freshwater flows from the catchment needs to be clarified.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Decrease of rainfall during Winter (Jan-Feb) - **High**	Mangroves are increasingly stressed during the dry season by increasing salinity in creeks. Growth and health during this season will be reduced	Appropriate water conservation, measures such as creating graded bunds, Sub-surface dykes - to be planned and facilitated by Water Resources department; and Forest, Environment and Climate Change Department.	Very High[1]	Very High[2]	High
		Release of water from reservoir appropriately to manage the salinity in the creak: Forest, Environment and Climate Change Department should coordinate with the Water Resources department.	Medium[3]	Medium[4]	Medium
		Monitoring the water quality and salinity in the Ramsar Site i.e., surface waters (including river, Khola creek, ponds, etc) and groundwater at various locations by the Water Resource department in collaboration with Forest, Environment and Climate Change Department.	High	High	High
	Freshwater flows from the catchment will be reduced further increasing salinity and reducing water quality	A study on Rainwater harvesting, recharge, water balance and other hydrological studies should be conducted in Bhitarkanika Ramsar Site. Water and soil conservation measures to be implemented in the catchment area	Very High[5]	Very High[6]	Very High

[1] Forest Department of Odisha has the technical competency, a cost-effective model and financial support could be supplemented from Environment & Climate Change action plan of the State Government.
[2] This measure would dilute the salinity of underground-water and provide protective moisture to the mangroves during the dry summer. This will provide a long term solution (Central Ground Water Board Government of India, manual on artificial recharge of ground water; September 2007; PP 96-98).
[3] The irrigation and hydropower projects are designed with priorities, supporting fisheries and the ecological services is internal and part of outcomes, rather than being exclusive.
[4] Reservoir water sometimes may not reach to mangrove area during the dry season as priority will be given to irrigation.
[5] Water and soil conservation technologies have already been adopted by the Forest Department in Odisha.
[6] Water and soil conservation will be the only sustainable measure for protection of mangroves.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
	The denudation or saline blank formations have been noticed in Bhitarkanika forest blocks, which is measured at 1700 acre. It said that the denuded patches, spotted in Mathadia, could be over 30 acres in this block area.	Plantation of Appropriate mangrove species in the denuded patches based on forest department studies and monitoring data. Forest, Environment and Climate Change Department. need to facilitated necessary plantation	Very High[7]	Very High[8]	Very High
TEMPERATURE					
Increase of temperature during the Monsoon (Jun-Oct) - **High**	The mangroves will be less productive due to the increase in temperature	Mangrove species tolerant to increase in temperature to be promoted	High	High	High
Increase in temperature during summer/ pre-monsoon (Feb to May) - **High**	The excessive salinity creates a blank formation over a period of time as the existing vegetation dies. (studies and continuous monitoring of water salinity in and around Bhitarkanika Ramsar site is recommended)	Recharge aquifer with rainwater in the mangrove forest area – measures such as Earthen Bunds, percolation ponds, Subsurface dykes, other appropriate technologies to be implemented by Forest, Environment and Climate Change Department.	High	High	High
		Release of water from reservoir appropriately to manage the salinity in the Khola creek- Water Resources department	Medium	Medium	Medium
		Monitoring the water salinity in the Ramsar Site area – Water resources department	High	High	High
		Plantation of Avicennia Alba/Officinalis which are highly saline resistance species. Felicitation of EDCs/Community for creation of new forest and forest protection efforts and also community should be provided with horticultural plants along with the mangrove associates for plantation in their lands and buffer zones – Forest, Environment and Climate Change Department	Very High[9]	Very High	Very High

[7] Plantation in denuded area is continuing by the Forest Department as a part of the management plan.
[8] Plantation will be sustainable with a decreased rainfall.
[9] Forest Department is focusing on re-plantation of mangroves in the management plan.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
Sea level rise – **Very High**	• Over reduction in Ramsar site area • Mangroves along the northern coastal section of the site, and along the central coastal strip will be lost amounting to approximately 20% of the forests[10]. • Also, fringing mangroves along creeks will be lost	The Water Resource Department has a plan to protect Odisha's coast which is vulnerable to tidal surges by the construction of 380 km. Saline embankment (stone and iron net structure) and massive plantation of Mangrove Associates along the embankment – In addition jointly Forest, Environment and Climate Change Department and Revenue Department identify open lands along the banks of the rivers and areas for buffer zones for plantation.	**Very High**[11]	**Very High**[12]	**Very High**
		Training of community on nursery rising, Plantation and maintenance. The focus should be given to the involvement of women. Communities should also be made responsible and accountable to plantation – Activity by Forest, Environment and Climate Change Department	**High**[13]	**High**	**High**
	• Mangrove forest species composition will change with the loss of saline intolerant species	Research/study on mangrove forest species composition that changes with saline gradient – by Forest, Environment and Climate Change Department in association with research organisations.	**High**[14]	**High**	**High**
Cyclone **–Very High**	Already cyclones have seriously damaged the mangroves – and systems under stress tend not to recover. The anticipated increase in cyclone occurrence and severity will lead to forest losses	Maintenance of density of frontline mangrove forest along the coastline to minimize the damage from wind velocity during cyclones - Forest, Environment and Climate Change Department	**Very High**[15]	**Very High**	**Very High**
		Maintenance of density of high cyclone resistance mangrove Phoenix Paludosa and Avicennia. Protection and increasing of density of Nelia grass - Forest, Environment and Climate Change Department	**Very High**	**Very High**	**Very High**
		Trimming of Phoenix Paludosa for maintaining density - Forest, Environment and Climate Change Department	**High**	**High**	**High**

[10] The natural adaptation response of mangroves to sea-level rise is to move inland – but in this case, there is little area for potential mangrove colonisation. On the other hand, mangroves accumulate sediments from the river and ocean currents and can raise the land level.
[11] Water Resource Department has planned for 380 km Saline embankment along with massive plantation of estimated cost 1944 crore (The economic times, 30th May 2021).
[12] Based on the sustainability of 52 km embankment constructed earlier.
[13] Forest Department can involve community in plantation program to encourage community participation in mangroves protection.
[14] The management plan of the Forest Department has a scope for including research study on Mangroves in relation to climate change.
[15] Forest Department is continuing and has further plan for maintenance of density of frontline mangrove forests along the coastline.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
Storm surge - **High**	Fringing mangroves along creeks will be lost	Maintenance of density of frontline mangrove forest cover along the coastline to minimize the damage from wind velocity during cyclones – Forest, Environment and Climate Change Department	**High**	**High**	**High**
	Mangrove seeds will be washed away which will minimize self-propagation	Maintenance of density of high cyclone resistance mangrove Phoenix Paludosa and Avicennia- Forest, Environment and Climate Change Department	**Very High**	**Very High**	**Very High**

Annex 3.3.1 - 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

Annex 3.4 - Adaptation Planning Matrix for Olive Ridley Sea Turtles

ASSET NAME: OLIVE RIDLEY SEA TURTLES

ASSET DESCRIPTION: Olive Ridley sea turtles form enormous congregations along the Odisha coast during the breeding season (November to April) with nesting taking place along suitable nesting beaches at Gahirmatha, Rushikulya and Devi rookeries. Gahirmatha is known to be the largest Olive Ridley's rookery in the World. Incubation takes about 60 days, but since the temperature of the sand governs the speed at which the embryos develop, the hatching period can cover a broad range. Essentially, the hotter the sand surrounding the nest, the faster the embryos will develop. Cooler sand has a tendency to produce more males, with warmer sand producing a higher ratio of females. The hatching occurs between the month of March and April in Gahirmatha sandy beach of Odisha. Estimates of annual turtle nesting in Gahirmatha have ranged between 100,000 to 800,000 in different years Historically, mass nesting has taken place along the 10 km of mainland coast in the Bhitarkanika Wildlife Sanctuary. However, from 1989 nesting became restricted to a 4 km long-isolated sand bar projecting into the Bay of Bengal. The super cyclone in 1999 fragmented the 4 km nesting beach into two islets namely Nasi-I & Nasi-II. The Defense Research and Development Organization (DRDO) have reported that mass nesting now takes place along a section just 900m long beach of the Wheeler Island, which is located at the tip of the sand bar.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
Increase in temperature during summer/ pre-monsoon (Feb to May) - **High**	The mass nesting site is vulnerable to changes in temperature under high nest density conditions that make embryo development impacted especially when incubation temperatures fluctuate around 3°C or less than the pivotal temperature may result in the exclusive production of a single-sex.	Regular monitoring of the temperature of the mass nesting beach during the incubation period – Forest Department (Wildlife)	Very High	Very High[1]	Very High
		Provide shed to the rookeries to maintain an appropriate temperature for the development of embryos – Forest Department (Wildlife)	Very High[2]	Very High	Very High
		Spray / Sprinkle water on the rookeries to maintain temperature – Forest Department (Wildlife)	Very High	Very High	Very High
	The quality and performance of Olive Ridley hatchlings will be poor in case of crawling speed, self-righting time and self-righting propensity that may lead to high mortality rates while travelling back to sea due to the rise in temperature beyond 34°C	Capacity Building of the staffs and volunteers (EDC / Community members on best practices of Olive Ridley Turtle monitoring and management – Forest Department (Wildlife)	Very High[3]	Very High	Very High
		Deployment of trained staffs and volunteers during the incubation period for the protection of eggs and hatchlings from predators – Forest Department (Wildlife)	High	Very High	Very High

[1] Monitoring of the nesting beach temperature can be done easily utilizing trained volunteers.
[2] Monitoring and maintaining appropriate temperature during incubation period will ensure balanced hatchlings of both sex.
[3] Taking volunteers from the nearby locality for the capacity building will enhance the involvement of the community in the process and protection process will be strengthened.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
		Maintenance trained volunteers' database – Forest Department (Wildlife)	**High**	**Very High**[4]	**Very High**
		nstallation of temporary cordons/fencing in the outer boundary area of the nesting sites to restrict other animals / wild animals to the beach for the protection of eggs and hatchlings from predators – Forest Department (Wildlife) to coordinate with DRDO (Defence Research and Development Organization) and plan for the modalities.	**Medium**	**High**[5]	**High**
EXTREME EVENTS					
Sea level rise - **Very High**	Over reduction in sandy shoreline area due to erosion of sand-dunes and beach leads to a reduction in the availability of mass nesting area for Olive Ridley turtles.	Artificial hatching should be experimented with in the nearby natural beach- – Forest Department (Wildlife) to coordinate with DRDO (Defense Research and Development Organization) and plan for the modalities.	**High**	**Very High**[6]	**Very High**
		Repair and maintenance of the nesting beach making suitable for mass nesting – Forest Department (Wildlife) to coordinate with DRDO (Defence Research and Development Organization) and plan for the modalities.	**High**	**High**	**High**
Cyclones - **Very High**	Cyclones with severe intensity will damage the sandy beach may further submerge and restrict the Olive Ridley turtles from mass nesting. (Further research studies should be conducted to understand the impact of cyclones affecting the sea turtles during the congregation period)	Artificial hatching should be experimented in the nearby natural beach- Forest Department (Wildlife) to coordinate with DRDO (Defense Research and Development Organization) and plan for the modalities	**High**	**Very High**	**Very High**
		Repair and maintenance of the nesting beach making suitable for mass nesting– Forest Department (Wildlife) to coordinate with DRDO (Defence Research and Development Organization) and plan for the modalities	**High**	**High**[7]	**High**

[4] Trained volunteers database will be helpful in immediate deployment of trained ones at the time of emergency requirement.

[5] It is little challenging to establish cordons but very effective to protect the eggs and hatchlings from predators.

[6] Using heavy machineries, the creation of new sand-dunes are possible and very effective to provide more breading and nesting space for the turtles.

[7] Sea-level rise may damage the mass nesting site which can be repaired before the nesting season as thousands of turtles may go back if the beach will not be suitable for mass nesting.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
Storm Surge - (Moderate to high risk of up to 5 m storm surge) - **High**	Moderate to high risk of storm surge (up to 5 meters) may result in the death of turtles that are normally congregated close to the shoreline waiting for breeding and mass nesting and The sand-dunes and beaches will be eroded due to tidal surge and the nesting site will be unsuitable for mass nesting of turtles due to mud layers on the top of the sands.	Artificial hatching of the sea turtle eggs facility should be established close to the nesting area, this would reduce the mortality of Turtles and Hatchlings – Forest Department (Wildlife) to coordinate with DRDO (Defense Research and Development Organization) and establish the hatching facility.	High	Very High	Very High
		Repair and maintenance of the nesting beach making suitable for mass nesting– Forest Department (Wildlife) to coordinate with DRDO (Defense Research and Development Organization) and plan for the modalities	High	High	High
		Clearance of the mud layers (after the storm surge) from the top of the sand/sand-dunes of the nesting beach to make it suitable for mass nesting – Forest Department (Wildlife).	High	Very High[8]	Very High
	The return tidal wave water may wash away the eggs from the nesting sites and the number of hatchlings may reduce drastically if it takes place during the incubation period	Rearrange the rookeries and place the eggs to continue the incubation process– Forest Department (Wildlife).	High[9]	Very High	Very High
		Deployment of volunteers to provide a sand cover to the eggs from which the sand layer is washed away – Forest Department (Wildlife).	High	Very High	Very High
		Establishment of a hatching centre close to the mass nesting site for artificial incubation of the eggs of Olive Ridley Turtles– Forest Department (Wildlife) to coordinate with DRDO (Defence Research and Development Organization) and plan for the modalities.	Medium	Very High[10]	Very High

[8] In case of storm surge, there is chance of getting mud layers on the top of the sand which is not suitable for mass nesting. Hence, clearance of the mud layers will make the beach suitable for turtles for mass nesting.

[9] The washed eggs that collected in the nets should be rearranged in the beach with the help of trained volunteers and staffs and properly covered with sand to ensure proper hatching.

[10] In case of extreme events like; cyclones and storm surge, it would be helpful to have a hatching centre with regulated temperature and other required facilities to ensure artificial hatching of the eggs that are washed away.

Annex 3.4.1 - 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 3.5 - Adaptation Planning Matrix for Fisheries

ASSET NAME: FISHERIES

ASSET DESCRIPTION: Mangrove ecosystems serve as vital nursery grounds for the economically important nearshore fish and shellfish species. People in the Bhitarkanika Ramsar Site depend on fishing (freshwater, brackish water and marine) and aquaculture (Prawns) for livelihood. Fish also serves the food security of half a million migratory waterbirds of the Ramsar Site. Fish species diversity has been reduced although fish production increased over a period.

Despite a ban period imposed by the forest and marine department for conservation of aquatic species in the Bhitarkanika Ramsar Site, illegal river and marine fishing is continuing in parts of restricted areas. The Indian Fishery Act for the protection of the Ramsar site - departments like Forest & Wildlife, Marine Fishery, inland Fishery, Water resource and revenue facilitate the implementation of these laws for the protection of Ramsar Site.

In the villages in Ramsar Site, aquaculture ponds are increasing[1]. Also, Fishery Department, Kendrapara District within Ramsar Site implements various livelihood schemes related to fish production and marketing. There is an impact on fisheries due to the polluted effluents entering from the catchment areas into the Ramsar Site water bodies, the sources of pollution are from industries, mining areas, aquaculture farms, agriculture chemicals, domestic pollution, etc. Climate Change has also impacted fish populations and species diversity.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
PRECIPITATION					
Decrease of rainfall during the dry season. (Feb-May) - **High**	Less freshwater in rivers, creeks, and ponds, will impact fish species and availability in numbers as they will be more easily consumed by dependent birds and animals (-ve)	Release of water from reservoirs upstream to increase the freshwater flows into the rivers and creeks for reducing the salinity in the wetland – Fisheries & Animal Resources Development Department, and Forest, Environment and Climate Change Department to work with water resources department and have modalities for scheduling the water releases.	**Medium[2]**	**High[3]**	**High**
	The pollution level in the water bodies increases impacting the fisheries habitats (-ve)	Compliance with the Odisha state pollution control Board norms for all the sectors causing pollution – pollution control board and local communities in the zone of influence must act.	**Medium[4]**	**Medium[5]**	**Medium**

[1] Cooperation needed from the Fisheries Department, Orissa State for controlling prawn culture in an eco-sensitive zone, which would also impact the native fish population due to effluents and excess drawl of water.
[2] The irrigation and hydropower projects are designed with priorities, supporting fisheries and the ecological services is internal and part of outcome, rather being exclusive.
[3] During drought years it becomes even more essential and sometimes there may not be water to release.
[4] The pollution sources are many (industrial, mining, sewerage, agriculture, etc) and the catchment area is large (51822 km2).
[5] In spite of compliance by the stakeholders to control pollution - by location this area is in the downstream, so there will be accumulated and residue pollutants in the water bodies.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
TEMPERATURE					
Increase of temperature during the winter (Nov–Jan) - **High**	The lack of oxygen in waters due to the increase in temperature leads to less existence of fish and aquatic life. (-ve)	Release of water from reservoirs upstream to increase the freshwater flows into the rivers and creeks for reducing the salinity in the wetland – Fisheries & Animal Resources Development Department and Forest, Environment and Climate Change Department to work with water resources department and have modalities for scheduling the water releases.	**Medium**[6]	**High**[7]	**High**
EXTREME EVENTS					
Sea level rise - **High**	• Habitat for spawning and growth of marine and brackish water fish will be reduced (-ve)	Release of water from reservoirs upstream to increase the freshwater flows into the rivers and creeks for reducing the salinity in the wetland and build dykes. Demarcation of the sanctuary area needs to be shared among line departments and the community and create awareness to avoid encroachments. Permission for freshwater aquaculture in the buffer zone to discourage brackish water aquaculture: Fishery and Forest Department. - The following departments should work together for compliance, Fisheries & Animal Resources Development Department; Revenue Department and Forest, Environment and Climate Change Department.	**Medium**[8]	**Low**[9]	**Medium**
	• Freshwater fish will tend to be replaced by brackish water fish as sea-level rise will lead to water salinity. (-ve)	Introduction of suitable freshwater fishes tolerant to increase in salinity and create awareness among the community members especially women on various freshwater fish-farming schemes of Fishery department for alternative livelihood options - Fisheries & Animal Resources Development Department could facilitate through its programs.	**High**[10]	**High**[11]	**High**

[6] The release of water depends on the priorities of the irrigation department.
[7] During drought years it becomes even more essential and sometimes there may not be water to release.
[8] The release of water depends on the priorities of irrigation department and building dykes is a costly intervention, depends on budgetary allocations.
[9] Building dykes is costly and may not ensure complete protection.
[10] Fisheries Department by involving local communities could introduce the suitable fishes – assessment of the suitable fishes is possible through consultations with stakeholders and referencing the scientific studies.
[11] Need to also conserve the fisheries biodiversity of the area.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
Cyclones - **High**	• Cyclones will impact the fish habitats and there will be less fish with an increased number of cyclones. (-ve)	Activities to regenerate the mangroves habitat (plantation, protection, and conservation) and management of creeks and distributaries such as desilting – incorporating into the Forest, Environment and Climate Change Department, Fisheries & Animal Resources Development Department work plans and water resources department work plans.	**Medium**[12]	**High**[13]	**High**
Storm surge - **High**	• The saltwater intrusion into the habitat will affect the fish diversity and availability (-ve)	Release of water from reservoirs upstream to increase the freshwater flows into the rivers and creeks for reducing the salinity in the wetland and build dykes – Fisheries & Animal Resources Development Department, Forest, Environment and Climate Change Department to work with Water Resources department and have modalities for scheduling the water releases and build dykes.	**Medium**[14]	**Low**[15]	**Medium**

Photo credit: GIZ (Shambhavi)

[12] Budget allocations to the work plans by the respective departments will be in a phased manner.

[13] Plantation of mangroves and de-siltation is not a permanent solution to cyclones.

[14] The release of water depends on the priorities of the irrigation department and building dykes is a costly intervention, depends on budgetary allocations.

[15] Building dykes is costly and may not ensure complete protection.

Annex 3.5.1 - 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 (Shambhavi)

Annex 3.6 - Adaptation Planning Matrix for Tourisms

ASSET NAME: BHITARKANIKA – TOURISM

ASSET DESCRIPTION: Bhitarkanika National Park (BNP) was declared as a National Park on 16 September 1998. It obtained international importance as Ramsar site on 19th August 2002. Bhitarkanika tourism has got attraction for the Natural lush green mangrove forest, largest saltwater crocodile sanctuary, Asia's largest mixed-species heronry, (Bagagahana & Matha-Adia), numerous wild animals in mangrove forests and unique vast nesting ground beach of Olive Ridley (Gahirmatha). The Bhitarkanika National Park is open for tourism from January to April and August to December, however, the peak season for tourism is from October to February. Annually around 50,000 tourists visit Bhitarkanika.
Tourism is increasing every successive year (only with exception of fewer tourists due to the Covid pandemic in 2020-2021). The livelihoods related to tourism are increasing such as hospitality services - restaurants, canteens, lodging, homestay, boating, shops, local guides, etc. However, tourism in Bhitarkanika is a seasonal, secondary livelihood for a very small population from 20-25 villages that are close to the sanctuary area. Growth of service industry - hotels and restaurants and other allied sections - is very slow as many of the tourists are floating population, who return back on the same day after visiting other preferred places for staying overnight.

Climate change and anthropogenic activities are adding more risk in the area affecting tourism. The knowledge of ecotourism operators on the safe disposal of garbage is poor. At time of heavy rain and flooding situation, all the garbage are getting into the river/creeks nearby and causing pollution.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
Sea level rise – **Very High**	• Coastline erosion and change in biodiversity of mangroves will contribute to the reduction of the attractiveness of the Bhitarkanika site as the major habitat. (-ve)	Develop the high areas (above the submergence level due to the projected sea-level rise) in and around the existing tourist places. Accordingly develop mangroves above the submergence zone so that the wildlife shifts to the new protected areas; Build Dykes – Forest, Environment and Climate Change Department should design, plan, and implement.	**Medium[1]**	**Medium[2]**	**Medium**
	• Visitors to Bhitarkanika will be less (-ve)	Innovate other means of tourism in the submerged areas such as increase boating, create watch towers, create floating restaurants, and Houseboats at Hukitola or Dhamara. Training to be provided to the tourist guides on nature and conservation practices to facilitate tourists professionally. Also, they should be facilitated for alternative sources of income to cope with lean periods and reduced tourists. Odisha Tourism Development Corporation Ltd and Forest, Environment and Climate Change Department could plan and implement.	**High[3]**	**Medium[4]**	**Medium**

[1] Sea-level rise is a permanent encroachment, there will be limitations to all the adaptation options mentioned, building dykes would be very costly for the government, which could be implemented in a phased manner.
[2] Created high areas might get eroded during high rainfall and flooding, needs to be maintained.
[3] Highly feasible with the participation of the OTDC, FECC Departments and other ecotourism agencies.
[4] The tourists originally attracted to mangroves, siting wildlife and migratory birds may not appreciate any alternative tourist attractions.

Threats (High & Very High)	Impacts (direct impacts)	Adaptation options	Priority adaptation		
			Feasibility	Effectiveness	Priority
EXTREME EVENTS					
Cyclones - **Very High**	• Damage of Tourism assets like boats, petty shops (-ve)	Create awareness among tourism operators on the insurance of various assets susceptible to damage during extreme events and build insurance systems to protect the tourism assets like boats, hotels, petty shops, etc. – Revenue & Disaster Management Department, District administration and Odisha Tourism Development Corporation Ltd need to facilitate.	**High**[5]	**High**[6]	**High**
	• Disruption of communication and damage to roads. (-ve)	Restore the communications and maintain roads – respective telecommunications departments/agencies to ensure. Roads to be maintained – Works department Odisha to maintain.	**High**[7]	**Medium**[8]	**Medium**
	• Damage of Mangroves will affect the birds nesting which may lead to sift of nesting places resulting in less attraction for tourists.	Identify the vulnerable nesting areas and ensure the protection of the birds nesting sites by improving the mangroves in the area – Forest, Environment and Climate Change Department to take measures and incorporate in work plans.	**Medium**[9]	**Medium**[10]	**Medium**
Storm surge - **Very High**	• Loss of income from tourism sector (-ve)	Take measures for the protection of the area such as develop dykes, develop high rise areas and develop disaster resilient infrastructure to protect the tourists – Works Department, Water Resources Department, and Forest, Environment and Climate Change Department should design and implement the measures.	**Medium**[11]	**Medium**[12]	**Medium**

[5] Insurance mechanisms for assets are existing and very much possible, the government should support and encourage stakeholders for insurance.
[6] The insurance agencies would insist on disaster resilient infrastructure and assets to be eligible for insurance. However, many poor communities may not be able to do insurance.
[7] The government departments have work plans for development of roads and improve communications.
[8] With recurring increased frequency of cyclones there would be damage, roads to be maintained and communications restored for tourists.
[9] Feasible but requires time, would affect the migratory and local birds nesting pattern which will affect the tourists visits to the area.
[10] As the cyclones are recurring, in spite of the measures there would be damage to mangroves and the nesting sites.
[11] The measures suggested are costly to adopt but the measures are also relevant to many other assets protection and conservation.
[12] Storm surges would be recurring, the measures may not be adequate.

Annex 3.6.1 - 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

9.4 Annex 4 – Summary of Adaptation Strategies for Site Managers

9.4.1 Off-site management and adaptation measures

9.4.1.1 Ensuring freshwater flows to the wetland

Decreased rainfall and increased temperature will lead to increased salinity in the water of the Brahmani and Baitarani river basins. The baseline confirms a trend in salinity increasing at all stations. The adaptation plan will need to include measures for:

- Release of water from reservoirs upstream during the dry season (February – May) to increase the freshwater flows into the rivers and creeks for reducing the salinity in the wetland.
- Recharge of maximum rainwater into an aquifer in the mangrove forest area through various rainwater conservation methods (such as earthen bunds and sub-surface dykes) to dilute the sub-surface salinity.
- Saline embankment with green wall fencing along the coast to reduce the impact of the sea-level rise and tidal surges.
- Introducing suitable freshwater fishes that are tolerant to increases in salinity.

Photo credit: GIZ (Shambhavi)

9.4.1.2 Catchment management

Adaptation measures in the catchment need to include:

- Recharge rainwater into aquifers through a network of nature-based and hybrid approaches such as gully plugs, contour bunds, gabion structures and check dams.
- Ensure adequate environmental flows in rivers and streams to maintain ecological health and water quality through equitable and ecosystem-based management of reservoirs in the catchment area.
- Plan and implement irrigation water use efficiency and scheduling to ensure the water is available for drinking and ecosystem services.
- The preparation with all stakeholders and sectors of a river basin plan to introduce water demand management and ecosystem-based approaches to rehabilitation of the catchment and appropriate cumulative environmental assessment of existing and planned developments.
- Introduction of a rigorous monitoring and information sharing programme for the hydrology of the basin and early warning to reduce the intensity of floods and lessen the damage.

9.4.1.3 Pollution control

The catchment is suffering from increasing levels of pollution. The pollutants find their way into the Ramsar site, affecting its conservation and tourism values. A more concerted programme of controls, monitoring and reporting, and enforcement is required basin-wide with a clear definition of development sector compliance obligations. Increased resources need to be applied to communications and awareness-raising among all stakeholders on the causes and sources of pollution and the ways to reduce it at the source and minimise damage.

9.4.2 On-site management measures

9.4.2.1 Habitat restoration and management

Key adaptation measures for habitat restoration and management include:

- Demarcation of the sanctuary area is shared among line departments and communities, and awareness is created to avoid encroachments.
- Giving ecosystem-based adaptation and nature-based solutions priority in the site management plan.
- Progressive establishment of habitats in high areas above zones to be submerged by the sea-level rise.
- Planting of mangroves above the submergence zone so that the wildlife can shift to newly created habitats.
- Identifying vulnerable bird nesting sites and ensuring their protection by improving the mangroves in these areas.
- Regular excavation of the sub-creeks for maintaining the water levels required for crocodile habitation.
- Protection of mangroves on the river and creek sides to protect crocodiles from extreme events such as cyclones and tidal surges.
- Rehabilitation of mangrove habitats through plantation, monitoring and maintenance and management of creeks and distributaries, including desilting.
- Repair and maintenance of the nesting beach in preparation for the mass nesting of sea turtles, including clearance of the mud layers after storm surges from beaches and sand dunes.

9.4.2.2 Species support and management

Species-specific adaptation measures include:

- Plantation of more saline-resilient varieties of mangrove.
- Protection of crocodiles from increased temperature through maintenance of mangrove density along the Khola Creek and artificial rearing of crocodile hatchlings by the Forest Department.
- Providing shade and regular spraying of water from the sea on the turtle rookeries to maintain the appropriate temperature for the development of embryos.

- Deployment of trained staff members and volunteers during the incubation period of turtles for the protection of the eggs and hatchlings from predators, including installation of temporary cordons/fencing along the outer boundary of the nesting sites.
- Rearranging the locations of the rookeries and eggs to continue the incubation process in case of tidal surges, including providing sand cover to the eggs when a sand layer is washed away.
- Introduction of a programme for artificial hatching.

9.4.2.3 Livelihood support and management

Local communities and livelihoods are an essential part of the Ramsar site management and conservation. Adaptation measures required include:

- Community forest management undertaken by communities with support from the Forest Department.
- Awareness generation among community members on the information and coordination mechanism, which will protect the crocodiles trespassing into human habitats during flooding and tidal surge situations.
- Create awareness among the community members, especially women, on various freshwater fish-farming schemes of the Fishery Department for alternative livelihood options.
- Innovate other means of tourism in the submerged areas such as increase boating, creation of watchtowers and floating restaurants and houseboats at Hukitola or Dhamara with appropriate environmental safeguards.
- Training for tourist guides in nature and conservation practices and support for the application of conservation-oriented tourist programmes to be implemented by guides with needed support. Guides also to be supported in defining alternative sources of income to cope with lean periods and reduced tourists, including engagement in conservation management activities.
- Create awareness among tourism operators on the insurance of various assets susceptible to damage.
- Restoration and maintenance of communications and road and path networks after extreme events.

9.4.2.4 Addressing sea-level rise

- For the sea-level rise, a new regime of water releases from reservoirs upstream is required to increase and maintain freshwater flows into the rivers and creeks and reduce the salinity in the wetland.
- Identification of areas of mangroves likely to be inundated permanently by the sea-level rise and areas where mangroves need to be planted in the future.
- Carry out research into the protection of turtle nesting beaches and the creation or identification of alternative nesting beaches as existing sites become inundated by the sea-level rise.

Photo credit: GIZ (Shambhavi)

9.4.2.5 Protection against extreme events

- Priority should be given for plantation of short-height mangrove associate varieties to minimise the damage to mangrove forest during cyclones.
- The siting, design and materials for a network of dykes need to be carefully assessed as a strategy to protect the Ramsar site against submergence due to cyclones/tidal surges/the sea level rise.

9.4.3 Monitoring, survey and research

- Implementation of a comprehensive and adequately funded programme of monitoring, reporting and research to ensure continuing guidance to Ramsar site managers and wide communication of evolving conditions within the site and appropriate management innovations.
- Research and survey of mangrove forest species composition and changes with a saline gradient.
- Regular monitoring of the temperature of the mass nesting beach during the incubation period of March and April.
- Capacity building of the staff and volunteers on best practices of Olive Ridley Turtle monitoring and management.

Photo credit: WISA (Harsh)

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